



ALZHEIMER'S: HOW EMERGING GENE EDITING STRATEGIES COULD TRANSFORM TREATMENT

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Abstract

Despite decades of research and testing, Alzheimer's disease remains a progressive and currently terminal neurodegenerative disorder which affects over 55 million people across the world. It is a leading cause of mortality among the elderly without a full cure. Treatments for Alzheimer's primarily try to temporarily reduce amyloid-beta and tau accumulation in the brain, with these types of treatments being temporary. The effects of Alzheimer's, including neuroinflammation, memory loss, and metabolic stress, renders Alzheimer's disease one of the most prevalent neurodegenerative conditions to date. This paper aims to find theoretical methods and solutions to improve Alzheimer's treatment. Biomarkers, such as p-tau217, p-tau181, A-beta42/40 ratios, and neurofilament can also be used for early Alzheimer's detection. These biomarkers can enable earlier and more accurate detection of this disease, giving us the opportunity for earlier therapeutic intervention and treatment of Alzheimer's in patients.

Gene editing technologies have emerged as promising strategies to modify amyloid-beta and tau production to alleviate Alzheimer's. While CRISPR-Cas9 has seen success in reducing amyloid and tau production, several underused genetic tools, such as TALENs, Zinc Finger Nucleases, base and prime editors, and the newly developed seekRNA, offer unique advantages in precision or large scale DNA modification when dealing with mutations and diseases, especially with Alzheimer's. However, challenges such as side effects, size, and the blood brain barrier are still formidable obstacles; continued innovation in delivery systems, including engineered AAV capsids, lipid nanoparticles, and focused ultrasound, has the possibility to enable safe and effective deployment of these tools inside of the brain and central nervous system. Together, with a combination of these methods, these strategies offer a theoretical framework for future Alzheimer's modifying therapies that may one day move beyond symptom management.

Keywords

Alzheimer's; Gene Therapy; seekRNA; tau tangles; TALENs; amyloid-beta

Introduction

Alzheimer's disease is one of the most prevalent neurodegenerative disorders, affecting more than 55 million people worldwide and accounting for the majority of global dementia cases. As global life expectancy continues to rise, the prevalence of Alzheimer's is projected to proportionally increase, imposing a significant socioeconomic burden and pressure on patients, families, and healthcare systems. Despite decades of research, Alzheimer's currently remains incurable, and current therapies only offer temporary symptomatic relief rather than meaningful progress against the disease. This problem reflects the biological complexity of Alzheimer's, which involves far more than the accumulation of amyloid-beta plaques and tau tangles.



At the molecular level, Alzheimer's disrupts multiple interconnected systems within the brain. Protein aggregation impairs neuronal communication, while mitochondrial dysfunction reduces energy production and increases oxidative stress. Chronic neuroinflammation, driven by dysregulated microglia and astrocytes, accelerates neuronal death, causing neurodegeneracy. These overlapping mechanisms make it difficult for single target drugs to halt or reverse disease progression. Although recent advances in diagnostics, such as plasma p-tau217, p-tau181, A-beta42/40 ratios, and neurofilament, now allow earlier and more accurate detection, a single full cure at the moment is still lacking.

The emergence of gene editing technologies offers a new promising direction. While CRISPR-Cas9 is currently the most widely utilized gene editing tool in Alzheimer's research, a broader landscape of gene editing technology, including TALENs, Zinc Finger Nucleases, base and prime editors, and seekRNA, may provide safer or more precise approaches for targeting the proteins which cause Alzheimer's disease. Understanding these tools, their advantages, and their limitations, allows for the best pathway in the future in which we move beyond symptom management and toward true disease modification towards diseases such as Alzheimer's. This paper examines and proposes current and new untested biological foundations of Alzheimer's, evaluates current and emerging gene editing strategies, and explores the delivery challenges that must be overcome to translate these technologies into effective treatments

Methods

This paper is a theoretical review based on analysis of peer reviewed scientific literature related to Alzheimer's disease, diagnostic biomarkers, and emerging gene editing technologies. Research articles, clinical trial reports, and authoritative reviews were examined to evaluate mechanisms and effects of Alzheimer's disease. Additional sources were used to identify different gene editing technologies, such as TALENs, seekRNA, etc. Different technologies, while some have not been tested against Alzheimer's at the time of publication, were analyzed on their potential efficacy for fighting against Alzheimer's. Sources and references were gathered from databases such as the National Institutes of Health, Google Scholar, PubMed, and other scientific databases.

Results and Discussion

Background on Alzheimer's Disease

Alzheimer's disease still remains a significant challenge in our society today, with more than 55 million worldwide having dementia, the majority of whom have Alzheimer's disease (Gustavsson et al. 2022). Alzheimer's disease is a progressive neurodegenerative disorder of the brain which slowly destroys memory and thinking ability, and eventually leads to severe cognitive decline, in which people are unable to complete simple tasks (National Institute of Aging 2023). As global life expectancy increases, the number of individuals affected by Alzheimer's is expected to sharply rise in coming decades, making it important to find a solution or mitigator for Alzheimer's (Hao and Chen 2025).

Effects of Alzheimer's

Alzheimer's is caused by the abnormal buildup of proteins such as amyloid plaques and tau tangles (O'Brien and Wong 2011). These proteins damage neurons, disrupt communication, and cause shrinkage of the brain (Tyan et al. 2012). Alzheimer's causes mitochondrial dysfunction because the amyloid-beta and tau proteins impair neurons. This mitochondrial dysfunction impairs energy metabolism, increases oxidative stress, disrupts calcium homeostasis, and impairs mitochondrial transport (Wang et al. 2025).

Alzheimer's Detection



Alzheimer's detection is difficult, but there have been methods developed to try and predict if someone has Alzheimer's (National Institute on Aging 2024a). One such method involves monitoring the level of amyloid-beta plaques and tau tangles. By utilizing Positron Emission Tomography (PET) scans or cerebrospinal fluid (CSF) analysis, clinicians can measure the accumulation of these proteins inside of a patient (O'Brien and Wong 2011). This method utilizes the amyloid-beta plaques and tau tangles as biomarkers to measure if a person may have Alzheimer's. If they do show signs of having too much of either of these proteins, we can predict that a person may have Alzheimer's. Another method of detection we can use is the presence of the APOE-E4 allele. Unlike the neutral APOE-E3 allele or the neurological protective APOE-E2 variants, the E4 allele is associated with impaired amyloid-beta detection and clearance and heightened neuroinflammation (Bryant 2021). However, this method of detection can only work if the parents of the patient have passed down this allele, and considering that 14-15% of the population has the APOE-E4 allele, it is relatively common and can work well (Bryant 2021)

Current Treatment of Alzheimer's

While there are currently marketed treatments for Alzheimer's, they are not fixed treatments of Alzheimer's and mostly provide temporary relief by targeting symptoms (MDPI 2025; Liu et al. 2025). Most Alzheimer's treatments at the moment include drugs which remove amyloid-beta plaques; however, these are not permanent treatments and are instead temporary treatments which attack the symptoms (Alzheimer's Association 2019b). There are also drugs which address cognitive thinking and daily functioning, such as rivastigmine, galantamine, and benzgalantamine. However, these do not fix or mitigate Alzheimer's and are instead meant to help the brain function, overlooking the amyloid-beta plaques buildup entirely (Liu et al. 2025; National Institute on Aging 2023). Drugs and antibodies such as these only temporarily help, and can only help in earlier stages of Alzheimer's (Alzheimer's Association 2019b). The reason why there are currently no effective treatments for Alzheimer's is due to the complexity of the disease. Alzheimer's causes severe accumulation of amyloid-beta plaques and tau tangles, which disrupt the brain and start the massive apoptosis of neurons, leading to neurological decline over time and eventual death (O'Brien and Wong 2011). Alzheimer's disease also causes neurological inflammation, and due to Alzheimer's being present, microglia and astrocytes, cells which release chemicals to repair damage, into neurotoxic agents which actively drive for neurodegeneration and synapse loss, leading to severe neurological damage and eventual brain failure (Di Benedetto et al. 2022; Deng et al. 2023).

Gene Therapy & Biomarkers

Scientists have been doing extensive research on gene-editing technologies, such as CRISPR-Cas9 for preclinical Alzheimer's, and experimentation with Alzheimer's have shown promising results in reducing amyloid-beta plaques and tau proteins in animal models and human induced pluripotent stem cells (iPSCs) as biomarkers (Lu et al. 2021; Akbar et al. 2025). Additionally, scientists are successfully using CRISPR to edit and knock down genes associated with APP and PSEN1, and risk factors such as APOE-E4 alleles (Lu et al. 2021). While no human clinical trials have been conducted for CRISPR based on Alzheimer's, as of 2026, there have been other forms of gene therapy currently in phase 1 and phase 2 being tested in humans (He et al. 2025). For instance, researchers are investigating the usage of vectors to deliver protective genes directly to the central nervous system (He et al. 2025). While we are still in the early stages of determining long term efficacy and safety, these trials could show potential progress against Alzheimer's. Additionally, recent advances in biomarker research has made Alzheimer's detection more accurate and accessible. In addition to PET imaging and CSF analysis, clinicians are increasingly relying on alternative biomarkers which can detect Alzheimer's pathology with high sensitivity (Yim et al. 2025). Plasma phosphorylated tau proteins, such as p-tau217 and p-tau181, strongly correlate with tau accumulation in the brain and can be used to identify Alzheimer's even in its earliest stages (Yim et al. 2025). Other blood markers, including the A-beta42/40 ratio and neurofilament light chain (NfL), provide further detection of amyloid burden and neurodegeneracy (Borrelli 2026). These tests are less invasive and significantly



cheaper than traditional methods, making them promising tools for screening and early diagnosis of Alzheimer's. (Lomte 2026).

TALENs

There are also other, less experimented tools we could use to help with Alzheimer's with their own benefits and drawbacks. While CRISPR-Cas9 is often recognized as the best and only tool to assist Alzheimer's, there are many other theoretical tools we could use to mitigate Alzheimer's. One of these tools is Transcription Activator-Like Effector Nucleases (TALENs). TALENs, while it may be more expensive and inconvenient, are incredibly precise compared to other gene-editing tools such as CRISPR-Cas9 (Gupta and Musunuru 2014). TALENs are proteins which are engineered to bind to specific DNA sequences with an exact match between amino acid repeats and nucleotides (Chandrasegaran 2017). The highly accurate makes them a particularly good tool for targeting the APP gene, or silencing the APOE-E4 allele, as TALENs are less likely to cause unintended consequences (Chandrasegaran 2017). Beyond editing nuclear DNA, TALENs has also shown precision in editing mitochondrial DNA, which is often dysfunctional in patients with Alzheimer's (Wang et al. 2025). With the usage of TALENs, in vitro studies suggest we could also restore mitochondrial function in neurons for patients with Alzheimer's, and prevent metabolic failure which precedes cell death (Wang et al. 2025). Although TALENs are more complex to manufacture and are more costly, they are generally the safer option, especially for patients with neurodegenerative diseases, such as Alzheimer's (Gupta and Musunuru 2014).

seekRNA

Another recently developed tool is seekRNA. Unlike CRISPR-Cas9, which creates potentially harmful breaks in the DNA, seekRNA, a newly discovered gene therapeutic tool discovered in 2024-2025, is a programmable system which can precisely insert, remove, or invert large sections of DNA with less errors than CRISPR (Siddiquee et al. 2024; University of Sydney 2024). For Alzheimer's research, this is a significant advancement. Rather than simply silencing a risky allele such as APOE-E4, seekRNA could be used to theoretically put in a new allele such as the APOE-E2 allele directly into the patient's genome with near perfect accuracy (Siddiquee et al. 2024). Furthermore, due to seekRNA being a stand-alone tool as it requires only a single small protein and short RNA strand, it is significantly easier to package into viral vectors for delivery across the blood brain barrier (BBB) (Siddiquee et al. 2024). However, it is still in the early stages of development and adaptation to human cells, and is still preclinical. (University of Sydney 2024). We could also use base editors and prime editors as another method to mitigate Alzheimer's. Base editors and prime editors are able to convert one nucleotide into another (Eid et al. 2018; Chen and Liu 2022). This is relevant for Alzheimer's research, as it offers a method to convert the risk factored APOE-E4 into the neutral APOE-E3 variant by just changing two nucleotides (Kantor et al. 2020). Prime editing, on the other hand, is capable of performing all twelve possible base to base conversions, as well as small insertions and deletions of the DNA (Chen and Liu 2022). Because prime editors do not rely on double stranded breaks of the DNA, they significantly reduce the risk of tissues being damaged, known as p53 mediated toxicity (Eid et al. 2018; Gudkov and Komarova 2010). As of 2026, these technologies are being refined and improved upon for better delivery with lipid nanoparticles, providing a clear pathway on how we can correct familial mutations in the APP or PSEN1 genes with safety (Fletcher 2024; Lee et al. 2025).

Zinc Finger Nucleases (ZFNs)

Another method of helping with Alzheimer's is the usage of Zinc Finger Nucleases (ZFNs). ZFNs are hybrid proteins which are engineered to recognize three base paired sequences of DNA, allowing for highly precision based targeting of Alzheimer linked genes, such as MAPT, the gene responsible for tau protein production (Cradick et al. 2011). A distinct advantage of ZFNs is their minimal size. They are significantly smaller than the Cas9 proteins used by CRISPR, and due to this, they can be more easily packaged into single Adeno-Associated Virus (AAV) vectors for delivery across the blood brain barrier (BBB) (Cradick et



al. 2011; Chandrasegaran 2017). Furthermore, ZFNs trigger a lower immune system response compared to CRISPR, as ZFNs have mostly human-like protein structures (Cradick et al. 2011). Clinical explorations using ZFNs to repress the expression of the tau gene have demonstrated that reducing the sheer volume of tau production is possible, and can actively help for the fight against Alzheimer's (Chandrasegaran 2017).

Gene Silencing

We can also use gene silencing approaches such as Antisense Oligonucleotides (ASOs) and Small Interfering RNA (siRNA), and while they are not permanent fixes, they can be temporary mitigators for Alzheimer's (Kantor et al. 2020). ASOs are short, synthetic strands of nucleotides which bind to specific messenger RNA (mRNA) sequences in an effort to prevent further translation of toxic proteins (Kantor et al. 2020). Similarly, siRNA uses the natural RNA interface (RNAi) of the body to intercept and destroy harmful mRNA before it can be translated into protein (Kantor et al. 2020). While these are considered as temporary fixes, they are still applicable in Alzheimer's research, and should not be overlooked.

Table 1: Comparative Analysis of Gene Editing and Silencing Platforms

Technology	Primary Mechanism	Precision Level	Delivery Feasibility (Size)	Level of Evidence in AD
CRISPR-Cas9	Double-strand DNA breaks	High	Challenging (Large Cas9 protein)	Preclinical (Animal/iPSC models)
TALENs	Protein-DNA binding repeats	Very High	Difficult (Bulky protein pairs)	Preclinical / Theoretical
ZFNs	Zinc-finger protein motifs	High	Optimal (Smallest nuclease)	Preclinical
Base/Prime Editors	Single-nucleotide conversion	Exceptional	Difficult (Very large complexes)	Preclinical
seekRNA	Site-specific integration	Exceptional	High (Small, stand-alone system)	Theoretical / Discovery



ASOs / siRNA	RNA interference/silencing	Moderate	High (Small synthetic strands)	Clinical (Phase 1/2 Trials)
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Limitations and Challenges of Gene Therapy

Although gene editing technology offers enormous therapeutic potential, each therapeutic method has its own important limitations. TALENs, while highly precise, are difficult to design and produce, and their large protein size complicates delivery into neurons (Chandrasegaran 2017). Zinc Finger Nucleases (ZFNs) require complex protein engineering and can produce side effects if zinc finger arrays bind to unintended sequences (Cradick et al. 2011). Base editors and prime editors avoid breaking DNA into double strands but remain bulky, making them challenging to vectors, and prime editing shows relatively low efficacy in post-mitotic cells such as neurons (Eid et al. 2018; Lee et al. 2025). seekRNA, despite its promise, remains in early development, with not much data available (Siddiquee et al. 2024). Even ASOs and siRNA, which are clinically validated, require constant dosing and struggle to cross the BBB without specialized delivery systems (Kantor et al. 2020; Nature Reviews Materials 2021). These limitations highlight the need for continued gene therapy before they can be used against Alzheimer's. The most formidable issue throughout all of genetic therapy for Alzheimer's is the Blood Brain Barrier (BBB) (Nature Reviews Materials 2021). The BBB is a highly selectively permeable layer for the borders of endothelial cells, which protect the brains from external toxins and pathogens (National Institute on Aging 2024b). While this barrier is essential for survival, it also recognizes therapeutic agents such as AAV Vectors, CRISPR-Cas9 and ASOs as foreign threats, blocking over 98% of all small molecule drugs and nearly all larger genetic tools from entering the central nervous system (Nature Reviews Materials 2021; Padridge 2025). To bypass this barrier, researchers in 2026 are experimenting with focused ultrasound (FUS) with the guidance of MRI to temporarily bypass this barrier and allow all of these gene therapies to take effect (UVA Health 2025). Overcoming the blood brain barrier remains one of the greatest challenges in Alzheimer's gene therapy, but several strategies are emerging. Engineered AAV capsids, such as AAV9 and PHP.eB, are being optimized to pass the BBB more efficiently and target neurons with high specificity (Kantor et al. 2020). Lipid nanoparticles (LNPs), which have been successful in certain mRNA vaccines, are being adapted to deliver gene editing components directly to the central nervous system (Nature Reviews Materials 2021). Researchers are also exploring receptor mediated transcytosis, where therapeutic molecules are attached to ligands which bind to receptors (Nature Reviews Materials 2021). Additionally, exosomes are being engineered as delivery vehicles for RNA and therapeutics which could be potential progress against Alzheimer's (Nature Reviews Materials 2021). These approaches, combined with ultrasound, represent progress for bypassing the BBB and safely transporting gene editing technologies into the brain (UVA Health 2025). Additionally, most of these gene editing technologies are still in preclinical/discovery stages and have yet to be tested on humans. While Phase 1 and Phase 2 trials have begun for most technologies listed in this paper, the transition from testing upon animals into the central nervous system of humans requires further improvement of long term safety and more experimentation.

Future

Looking into the future, the future of Alzheimer's therapy will likely involve a combination of early detection of Alzheimer's with biomarkers, targeted gene editing with gene editing tools, and improved delivery systems (Yim et al. 2025; He et al. 2025). As blood based biomarkers enable earlier diagnosis, gene editing tools may be deployed before extensive neuronal loss occurs (Yim et al. 2025). This increases the likelihood of meaningful recovery and better treatment against Alzheimer's (He et al. 2025). Continued refinement of delivery technologies, such as AAV engineering, nanoparticles, and focused ultrasound, will be essential for safe transportation of therapeutic molecules across the BBB (Kantor et al. 2020; UVA Health 2025).



Ultimately, the most promising path forward may involve integrating multiple approaches: correcting genetic risk factors such as APOE-E4, reducing amyloid and tau production, restoring mitochondrial function, and reducing neuroinflammation (Gupta and Musunuru 2014; Wang et al. 2025). While significant challenges remain, the progress of gene editing technologies provide a hopeful foundation for future Alzheimer's treatments which address the disease at its roots rather than treating symptoms (Chen and Liu 2022).

Conclusion

Alzheimer's disease remains one of the most complex and devastating neurodegenerative disorders, driven by the accumulation of amyloid-beta plaques and neurofibrillary tau tangles (O'Brien and Wong 2011). Alzheimer's can cause mitochondrial dysfunction, more stress on metabolism, chronic neuroinflammation, and even death (Wang et al. 2025; Di Benedetto et al. 2022). Although modern diagnostics, particularly plasma biomarkers such as p-tau217, p-tau181, A-beta42/40 ratios, and neurofilament light chain now allow earlier and more accurate detection, current treatments still offer only temporary symptomatic relief (Liu et al. 2025; Yim et al. 2025). The emergence of gene editing technologies provides a promising path towards addressing the roots of the disease rather than its effects (Lu et al. 2021). While CRISPR-Cas9 has dominated early research, other tools with their own benefits and limitations are discussed in this research paper (Gupta and Musunuru 2014; Siddiquee et al. 2024). Significant challenges also remain, particularly in achieving safe and efficient delivery across the blood brain barrier and ensuring long term safety in post-mitotic neurons (Nature Reviews Materials 2021). Continued innovation in delivery systems will be essential for translating these tools into viable therapies (Kantor et al. 2020). As diagnostic capabilities improve and gene technologies advance, a future in which Alzheimer's can be treated at its genetic and molecular origins becomes more plausible (He et al. 2025). The integration of early detection, targeted editing, and optimized delivery may ultimately shift Alzheimer's therapy from symptom management towards true disease modification (He et al. 2025).

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References

Akbar, Amna, Rida Haider, Luisa Agnello, Bushra Noor, Nida Maqsood, Fatima Atif, Wajeeha Ali, Marcello Ciaccio, and Hira Tariq. 2025. "CRISPR in Neurodegenerative Diseases Treatment: An Alternative Approach to Current Therapies." *Genes* 16 (8): 850. <https://doi.org/10.3390/genes16080850>.

Alzheimer's Association. 2019a. "Earlier Diagnosis." Alzheimer's Association. <https://www.alz.org/alzheimers-dementia/research-and-progress/earlier-diagnosis>.

Alzheimer's Association. 2019b. "Medications for Memory, Cognition and Dementia-Related Behaviors." Alzheimer's Association. <https://www.alz.org/alzheimers-dementia/treatments/medications-for-memory>.

Alzheimer's Association. 2023. "New CRISPR/Gene Editing Strategies for Alzheimer's." AAIC. July 16, 2023. https://aaic.alz.org/releases_2023/crispr-gene-editing-treatment-potential-alzheimers.asp.

"Base Sequence Alteration." n.d. BioTopics. Accessed March 6, 2026. https://www.biotopics.co.uk/A20/Base_sequence_alteration.html.

Bentley, Emily P. 2025. "CRISPR 101: Cytosine Transversion Editors." Addgene. <https://blog.addgene.org/crispr-101-cytosine-transversion-editors>.



Borrelli, Lizette. 2026. "Blood Test Predicts Timing of Alzheimer's Onset." Medscape, February 25, 2026. <https://www.medscape.com/viewarticle/blood-test-predicts-timing-alzheimers-onset-2026a10005ww>.

Braininflammation. 2025. "What Is Brain Inflammation?" May 4, 2025. <https://braininflammation.org/learn/what-is-brain-inflammation/>.

Bryant, Erin. 2021. "Study Reveals How APOE4 Gene May Increase Risk for Dementia." National Institute on Aging. <https://www.nia.nih.gov/news/study-reveals-how-apoe4-gene-may-increase-risk-dementia>.

Chandrasegaran, Srinivasan. 2017. "Recent Advances in the Use of ZFN-Mediated Gene Editing for Human Gene Therapy." *Cell and Gene Therapy Insights* 3 (1): 33–41. <https://doi.org/10.18609/cgti.2017.005>.

Chen, Peter J., and David R. Liu. 2022. "Prime Editing for Precise and Highly Versatile Genome Manipulation." *Nature Reviews Genetics* 24 (24): 1–17. <https://doi.org/10.1038/s41576-022-00541-1>.

Cradick, Thomas J., Giovanna Ambrosini, Christian Iseli, Philipp Bucher, and Anton P. McCaffrey. 2011. "ZFN-Site Searches Genomes for Zinc Finger Nuclease Target Sites and Off-Target Sites." *BMC Bioinformatics* 12 (1). <https://doi.org/10.1186/1471-2105-12-152>.

"Cytosine." n.d. Genome.gov. Accessed March 6, 2026. <https://www.genome.gov/genetics-glossary/Cytosine>.

Deng, Qianting, Chongyun Wu, Emily Parker, Timon Cheng-Yi Liu, Rui Duan, and Luodan Yang. 2023. "Microglia and Astrocytes in Alzheimer's Disease: Significance and Summary of Recent Advances." *Aging and Disease*. <https://doi.org/10.14336/ad.2023.0907>.

Di Benedetto, Giulia, Chiara Burgaletto, Carlo Maria Bellanca, Antonio Munafò, Renato Bernardini, and Giuseppina Cantarella. 2022. "Role of Microglia and Astrocytes in Alzheimer's Disease: From Neuroinflammation to Ca²⁺ Homeostasis Dysregulation." *Cells* 11 (17): 2728. <https://doi.org/10.3390/cells11172728>.

Eid, Ayman, Sahar Alshareef, and Magdy M. Mahfouz. 2018. "CRISPR Base Editors: Genome Editing without Double-Stranded Breaks." *Biochemical Journal* 475 (11): 1955–64. <https://doi.org/10.1042/bcj20170793>.

Fletcher, Lyndsey. 2024. "Back to Basics - Base & Prime Editing." *Front Line Genomics*. February 28, 2024. <https://frontlinegenomics.com/back-to-basics-base-and-prime-editing/>.

Francisco, Hugo. 2026. "Blood Test Models Predict When Alzheimer's Symptoms May Start Years in Advance." *News-Medical*, February 22, 2026. <https://www.news-medical.net/news/20260222/Blood-test-models-predict-when-Alzheimere28099s-symptoms-may-start-years-in-advance.aspx>.

Fuster-Matanzo, Almudena, María Llorens-Martín, Félix Hernández, and Jesús Avila. 2013. "Role of Neuroinflammation in Adult Neurogenesis and Alzheimer Disease: Therapeutic Approaches." *Mediators of Inflammation* 2013: 1–9. <https://doi.org/10.1155/2013/260925>.

García-Domínguez, Mario. 2025. "Neuroinflammation: Mechanisms, Dual Roles, and Therapeutic Strategies in Neurological Disorders." *Current Issues in Molecular Biology* 47 (6): 417. <https://doi.org/10.3390/cimb47060417>.

Gudkov, A. V., and E. A. Komarova. 2010. "Pathologies Associated with the P53 Response." *Cold Spring Harbor Perspectives in Biology* 2 (7): a001180. <https://doi.org/10.1101/cshperspect.a001180>.



Gupta, Rajat M., and Kiran Musunuru. 2014. "Expanding the Genetic Editing Tool Kit: ZFNs, TALENs, and CRISPR-Cas9." *Journal of Clinical Investigation* 124 (10): 4154–61. <https://doi.org/10.1172/jci72992>.

Gustavsson, Anders, Nicholas Norton, Thomas Fast, Lutz Frölich, Jean Georges, Drew Holzapfel, Tunahan Kirabali, et al. 2022. "Global Estimates on the Number of Persons across the Alzheimer's Disease Continuum." *Alzheimer's & Dementia* 19 (2): 658–70. <https://doi.org/10.1002/alz.12694>.

Hao, Miao, and Jiajun Chen. 2025. "Trend Analysis and Future Predictions of Global Burden of Alzheimer's Disease and Other Dementias: A Study Based on the Global Burden of Disease Database from 1990 to 2021." *BMC Medicine* 23 (1). <https://doi.org/10.1186/s12916-025-04169-w>.

He, Cong, Baojiang Chen, Ciai Yan, and Xiaoqing Zhou. 2025. "Stem Cell and CRISPR/Cas9 Gene Editing Technology in Alzheimer's Disease Therapy: From Basic Research to Clinical Innovation." *Frontiers in Genome Editing* 7. <https://doi.org/10.3389/fgeed.2025.1612868>.

Kantor, Ariel, Michelle E. McClements, and Robert E. MacLaren. 2020. "CRISPR-Cas9 DNA Base-Editing and Prime-Editing." *International Journal of Molecular Sciences* 21 (17): 6240. <https://doi.org/10.3390/ijms21176240>.

Khanahmadi, Mohammad, Dariush D. Farhud, and Maryam Malmir. 2015. "Genetic of Alzheimer's Disease: A Narrative Review Article." *Iranian Journal of Public Health* 44 (7): 892.

Komaroff, Anthony L. 2023. "Can We Fix Alzheimer's Genes?" *Harvard Health*. November 2023. <https://www.health.harvard.edu/diseases-and-conditions/can-we-fix-alzheimers-genes>.

Lee, Jaesuk, Jiyeon Kweon, and Yongsub Kim. 2025. "Emerging Trends in Prime Editing for Precision Genome Editing." *Experimental & Molecular Medicine* 57 (7): 1381–91. <https://doi.org/10.1038/s12276-025-01463-8>.

Lin, Li. 2025. "Prime Editing: A Revolutionary Technology for Precise Treatment of Genetic Disorders." *Cell Proliferation*. <https://doi.org/10.1111/cpr.13808>.

Liu, Shiyu, Yuan Liu, Yabo Wu, and Yumin Xu. 2025. "Comparative Efficacy and Safety of Symptomatic Therapy and Disease-Modifying Therapy for Alzheimer's Disease: A Systematic Review and Network Meta-Analysis." *Frontiers in Neuroscience* 19 (November): 1656906–6. <https://doi.org/10.3389/fnins.2025.1656906>.

Lomte, Tarun Sai. 2026. "New Blood Biomarker May Detect Alzheimer's Pathology More Accurately." *News-Medical*, March 4, 2026. <https://www.news-medical.net/news/20260303/New-blood-biomarker-may-detect-Alzheimere28099s-pathology-more-accurately.aspx>.

Lu, Likui, Xi Yu, Yongle Cai, Miao Sun, and Hao Yang. 2021. "Application of CRISPR/Cas9 in Alzheimer's Disease." *Frontiers in Neuroscience* 15. <https://doi.org/10.3389/fnins.2021.803894>.

MedicalNewsToday. 2023. "Alzheimer's: Can a Blood Test Detect Disease 3.5 Years Before Diagnosis?" *South Florida Reporter*, February 2, 2023. <https://southfloridareporter.com/alzheimers-can-a-blood-test-detect-disease-3-5-years-before-diagnosis/>.

National Institute on Aging. 2024a. "What Causes Alzheimer's Disease?" July 2, 2024. <https://www.nia.nih.gov/health/alzheimers-causes-and-risk-factors/what-causes-alzheimers-disease>.



National Institute on Aging. 2023. "Alzheimer's Disease Fact Sheet." National Institute on Aging. National Institutes of Health. 2023. <https://www.nia.nih.gov/health/alzheimers-and-dementia/alzheimers-disease-fact-sheet>.

2024b. "What Happens to the Brain in Alzheimer's Disease?" January 19, 2024. <https://www.nia.nih.gov/health/alzheimers-causes-and-risk-factors/what-happens-brain-alzheimers-disease>.

Nature Reviews Materials. 2021. "Let's Talk about Lipid Nanoparticles." *Nature Reviews Materials* 6 (2): 99. <https://doi.org/10.1038/s41578-021-00281-4>.

O'Brien, Richard J., and Philip C. Wong. 2011. "Amyloid Precursor Protein Processing and Alzheimer's Disease." *Annual Review of Neuroscience* 34 (1): 185–204. <https://doi.org/10.1146/annurev-neuro-061010-113613>.

Pardridge, William M. 2005. "The Blood-Brain Barrier: Bottleneck in Brain Drug Development." *NeuroRX* 2 (1): 3–14. <https://doi.org/10.1602/neurorx.2.1.3>.

SciTechDaily. 2026. "Scientists Uncover the Hidden Mechanism behind FDA-Approved Alzheimer's Drug." February 28, 2026. <https://scitechdaily.com/scientists-uncover-the-hidden-mechanism-behind-fda-approved-alzheimers-drug/>.

Siddiquee, Rezwan, Carol H. Pong, Ruth M. Hall, and Sandro F. Ataide. 2024. "A Programmable SeekRNA Guides Target Selection by IS1111 and IS110 Type Insertion Sequences." *Nature Communications* 15 (1). <https://doi.org/10.1038/s41467-024-49474-9>.

Sydney, University of. n.d. "Beyond CRISPR: SeekRNA Delivers a New Pathway for Accurate Gene Editing." *Phys.org*. <https://phys.org/news/2024-06-crispr-seekrna-pathway-accurate-gene.html>.

Tyan, Sheue-Houy, Ann Yu-Jung Shih, Jessica J. Walsh, Hiroko Maruyama, Floyd Sarsoza, Lawrence Ku, Simone Eggert, Patrick R. Hof, Edward H. Koo, and Dara L. Dickstein. 2012. "Amyloid Precursor Protein (APP) Regulates Synaptic Structure and Function." *Molecular and Cellular Neuroscience* 51 (1-2): 43–52. <https://doi.org/10.1016/j.mcn.2012.07.009>.

University of Sydney. 2024. "Beyond CRISPR: SeekRNA Delivers a New Pathway for Accurate Gene Editing." June 25, 2024. <https://www.sydney.edu.au/news-opinion/news/2024/06/25/beyond-crispr-seekrna-delivers-new-pathway-accurate-gene-editing.html>.

UVA Health. 2025. "Focused Ultrasound." <https://www.uvahealth.com/treatments/focused-ultrasound>.

Wang, Shuguang, Zuning Liao, Qiying Zhang, Xinyuan Han, Changqing Liu, and Jin Wang. 2025. "Mitochondrial Dysfunction in Alzheimer's Disease: A Key Frontier for Future Targeted Therapies." *Frontiers in Immunology* 15. <https://doi.org/10.3389/fimmu.2024.1484373>.

Xing, Haonan, Song Yue, Runtian Qin, Xiaoxue Du, Yili Wu, Dongting Zhangsun, and Sulan Luo. 2025. "Recent Advances in Drug Development for Alzheimer's Disease: A Comprehensive Review." *International Journal of Molecular Sciences* 26 (8): 3905. <https://doi.org/10.3390/ijms26083905>.

Yim, Sohyun, Seongbeom Park, Kyoung Yoon Lim, Heekyoung Kang, Daeun Shin, Hyemin Jang, Michael Weiner, et al. 2025. "CT-Derived Brain Volumes and Plasma P-Tau217 for Risk Stratification of Amyloid Positivity in Early-Stage Alzheimer's Disease." *Alzheimer's Research & Therapy* 17 (1). <https://doi.org/10.1186/s13195-025-01870-z>.



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PROPOSAL OF A FEASIBLE SYNTHETIC ROUTE TO ORMOSIANINE A VIA RETROSYNTHETIC ANALYSIS

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Abstract

Ormosianine A, a novel quinolizidine alkaloid isolated from *Ormosia yunnanensis*, has demonstrated potential acetylcholinesterase (AChE) inhibitory activity, with a Half-Maximal Inhibitory Concentration (IC₅₀) value of 1.55 μ M, stronger than most Alzheimer's Disease (AD) drugs currently being used. Despite its therapeutic potential in the treatment of AD, the compound's natural extraction process is extremely inefficient, yielding only 6.0 milligrams of the compound from 8.0 kilograms of the plant. To address this limitation, this study promises a retrosynthetic route to Ormosianine A using commercially available starting materials. The retrosynthesis started with an oxidation level analysis, which is then followed by a number of disconnections and synthetic techniques, most notably the Stork-Danheiser method. Strategic choices like keeping an olefin and controlling proton acidity with protective groups increase the plausibility of the retrosynthesis route. While challenges such as the incorporation of nitrogen exist, processes like reductive amination offer viable solutions. Overall, this retrosynthetic plan lays out a practical foundation for the lab-scale synthesis of Ormosianine A.

Keywords

Ormosianine A; Retrosynthetic Analysis; Acetylcholinesterase Inhibitors; Alzheimer's Disease; Synthetic Organic Chemistry

Introduction

Alzheimer's Disease (AD) is a neurodegenerative disorder characterized by the deterioration of memory and cognitive function (Murray et al, 2013, p. 388). According to the cholinergic hypothesis, AD patients suffer from a decrease in the levels of acetylcholine (ACh), a neurotransmitter responsible for transmitting electrical signals from one nerve cell to another, due to its hydrolysis by the enzyme acetylcholinesterase (AChE). Therefore, AChE inhibitors are key to alleviating the effects of AD¹.

Numerous naturally occurring compounds from plants are potential sources of AChE inhibitors. For example, Rivastigmine, an AD medicine approved in 2000 by the FDA, originates from the initial compound physostigmine, which is a naturally occurring AChE inhibitor alkaloid. Similarly, Galanthamine and Huperzine A, extracted from *Galanthus spp.* and *Huperzia spp.* respectively, are widely used as AD medicine, yielding improved cognitive performance for their patients².

In 2023, the plant *Ormosia yunnanensis*, which had previously not been studied, was selected to extract compounds with AChE inhibitory activities. The compound Ormosianine A (Figure 1), among 15 other novel quinolizidine alkaloids, was isolated from the stems and leaves of the plant in powdered form and was determined by high-resolution electrospray ionisation mass spectrometry (HRESIMS) to have a molecular formula of C₂₀H₃₂N₂O₂. Ormosianine A was the strongest AChE inhibitor among active compounds extracted from *Ormosia yunnanensis*, with an IC₅₀ value of 1.55 μ M. These values are lower than Rivastigmine, Galantamine, and Huperzine A, with IC₅₀ values of approximately 501 $\pm$ 3.08, 4 $\pm$ 0.13, and 13.62 μ M, respectively^{3,4}. Moreover, Ormosianine A formed hydrogen bonds with serine at position 238 and histidine at position 480, both key residues of the catalytic triad in the crystal structure of the AChE enzyme, further showing its potential to inhibit AChE⁵. Taken together, these pieces of evidence all indicate that Ormosianine A is a strong candidate for alleviating AD symptoms.

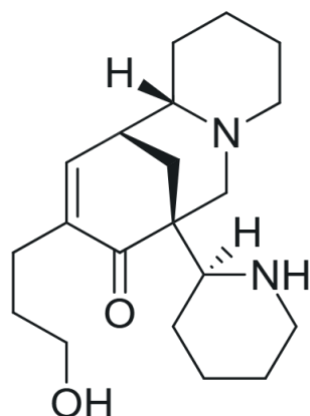


Figure 1. The structure of Ormosianine A, a novel quinolizidine alkaloid extracted from the plant *Ormosia yunnanensis*.

However, in the status quo, extracting Ormosianine A from nature and using it as a pharmaceutical is challenging. First, the plant *Ormosia yunnanensis* is native only to the subtropical biome of South and Central China, particularly Yunnan province, making the extraction of the compound in other parts of the world difficult. Second, the current extraction process has extremely low yields and is complicated, with 8.0 kilograms of the plant only yielding 6.0 milligrams of the compound, displaying a yield of $7.5 \times 10^{-5} \%$. The residue after powdering and extracting 8.0 kilograms of *Ormosia yunnanensis* with MeOH was 850 grams in mass. The residue was acidified, filtered, basified, and extracted with EtOAc to yield 40 g of total alkaloids. This was fractionated by silica gel chromatography into four parts (Fr. A–D). Compound 1 (6.0 mg) was isolated from Fr. B4 (2.0 g), a subfraction of Fr. B, via semipreparative HPLC using a MeOH / H₂O gradient⁵.

Despite the difficulties in extracting Ormosianine A from nature and its promising potential against AD, no prior study has suggested a synthetic route for the production of the compound. Therefore, to efficiently produce large amounts of Ormosianine A for AD treatment, this paper proposes a synthetic route from commercially available starting materials to Ormosianine A.

Background

This section defines two key chemical processes involved in the proposed retrosynthesis: oxidation level analysis and the Stork-Danheiser approach.

Oxidation level analysis helps synthetic chemists break complex target molecules into simpler precursors by assigning oxidation states to carbon atoms based on the number of electronegative atoms attached to them. Carbons bonded to no electronegative atom are assigned as alkane level, those bonded to one electronegative atom as alcohol level, those bonded to two electronegative atoms as aldehyde/ketone level, and those bonded to three electronegative atoms as acid level. Because molecules at the same oxidation level can often be interconverted with minimal transformation, chemists treat carbons as if they already possess the functional groups corresponding to their assigned oxidation levels. For example, if a carbon is assigned the alcohol level, it is assumed the carbon has one alcohol group attached to it, even if the actual functional group is different. After performing oxidation level analysis, chemists work toward synthesizing the simplified "oxidation-mapped" intermediate. Once this intermediate is obtained, it is then converted into the original target molecule since moving between molecules at the same oxidation level is typically straightforward.

The Stork-Danheiser approach is a synthetic strategy developed by Professor Gilbert Stork and his student Rick L. Danheiser for the stepwise installation of R groups onto a cyclohexane framework⁶. The sequence typically begins with 1,3-cyclohexanedione, a commercially available compound. Then, a series of chemical reactions ensues until the desired R groups are attached to the six-membered ring. Multiple variations of the Stork-Danheiser approach exist depending on how many R groups are to be incorporated and at which ring positions. Outlined below in Figure 2 is the specific variant employed in this study. The product of this variant produces a structure resembling the oxidation-mapped intermediate.

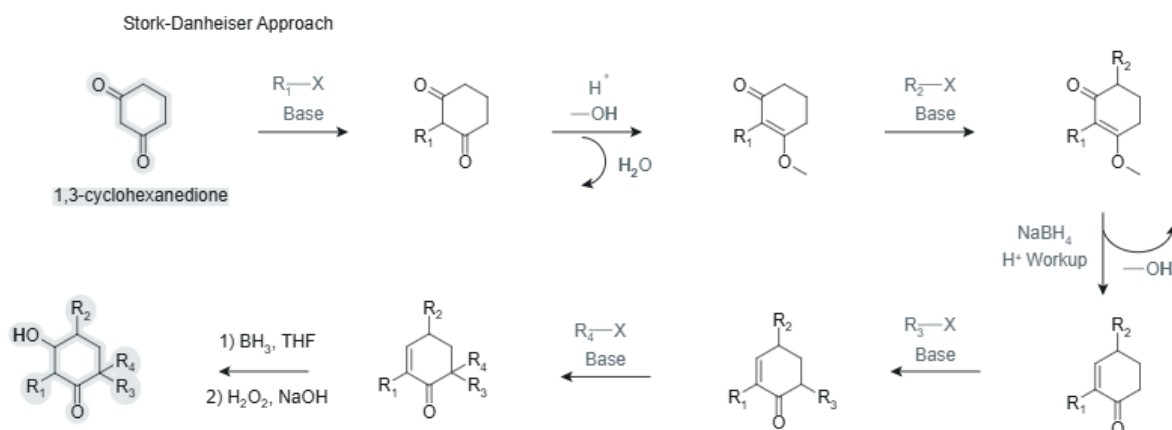
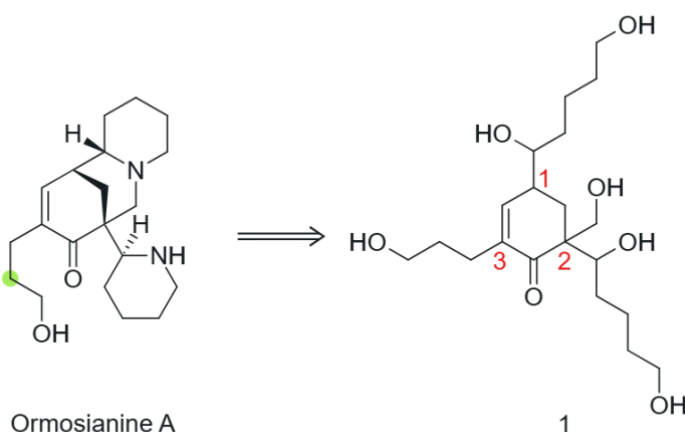


Figure 2. An illustration of the variant of the Stork-Danheiser approach, a synthetic strategy used to add side chains to a cyclohexane framework, employed in this study. The mechanism originates from Stork and Danheiser's seminal work, in which 1,3-cyclohexanedione is transformed into a more highly substituted cyclohexane⁶.

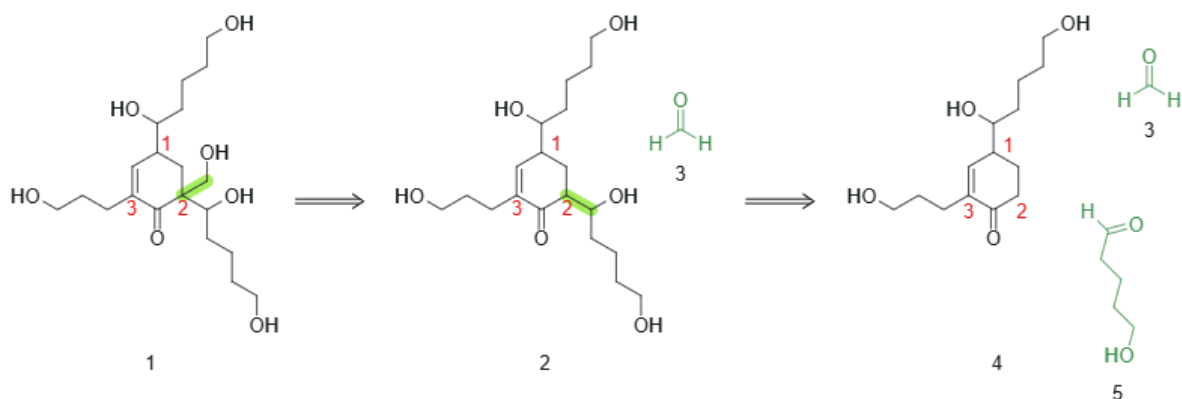
Results

The compound Ormosianine A was simplified into compound 1 via oxidation level analysis (Scheme 1). The result of the oxidation level analysis yielded a compound with a six-membered ring with R groups attached to three of its carbons. Even though the olefin on carbon 3 could have been eliminated via oxidation level analysis, it was intentionally retained to enhance the feasibility of the synthetic route, as demonstrated below.

Compound 1 was retrosynthesized into compound 2 by detaching the methanol group attached to carbon 2 (Scheme 2). Then, compound 2 can be further simplified into compounds 4 and 5 by detaching the butanol group attached to the same carbon. From a synthetic perspective, compounds 2 and 3 can be combined under basic conditions to form compound 1 if the alcohol groups are protected by being converted into ethers. Then, the most acidic protons would be attached to carbon 2, so the R groups will be attached to the following carbon. Likewise, compounds 4 and 5 can be coupled under basic conditions to generate compound 2.



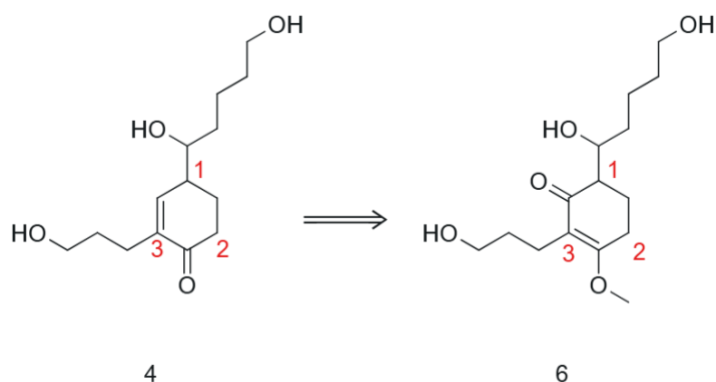
Scheme 1. A depiction of the oxidation level analysis of the compound Ormosianine A employed to simplify the molecule.



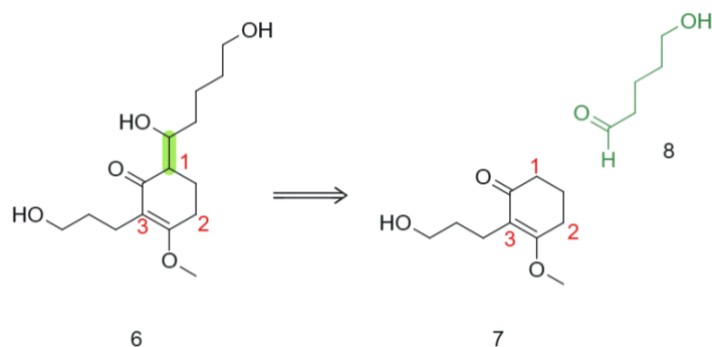
Scheme 2. Detachment of R groups attached to carbon 2. All green compounds from the current and subsequent schemes are commercially available and are therefore not further simplified.

Compound 4 was retrosynthesized into compound 6 following the implementation of the Stork-Danheiser approach (Scheme 3). Here, from a synthetic perspective, compound 6 can be converted into 4 by adding NaBH_4 and doing a H^+ workup, with methanol as a byproduct (Mechanism 1). Compound 4 is retrosynthesized into 6 in order to place the most acidic proton on carbon 1 so that Scheme 4 can take place.

Compound 6 was retrosynthesized into compounds 7 and 8 by detaching the butanol group from carbon 1 (Scheme 4). From a synthetic perspective, compounds 7 and 8 can be converted into compound 6 under basic conditions if the alcohol group in 7 is converted into an ether. Then, the most acidic proton would be located on carbon 1, so the R group would attach to that carbon.



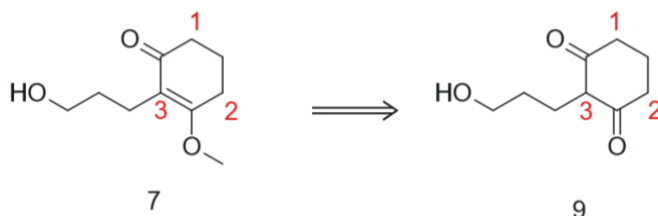
Scheme 3. Implementation of the Stork-Danheiser Approach (1). Adding NaBH_4 and protonating compound 6 produces compound 4 and methanol.



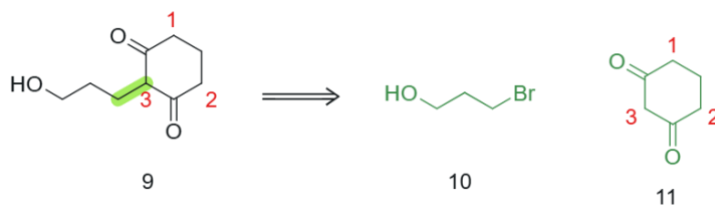
Scheme 4. Detachment of an R group attached to Carbon 1. Assuming the alcohol group in compound 7 is protected, adding compound 8 to compound 7 under acidic conditions would produce compound 6.

Compound 7 was retrosynthesized into compound 9 following the implementation of the Stork-Danheiser approach (Scheme 5). Here, from a synthetic perspective, compound 9 can be converted into 7 by adding methanol and an acid, with water as a byproduct (Mechanism 2). Compound 7 is retrosynthesized into 9 in order to remove the olefin and place the most acidic proton on carbon 3 so that Scheme 6 can take place.

Compound 9 was retrosynthesized into compounds 10 and 11 by detaching the propanol group from carbon 3 (Scheme 6). From a synthetic perspective, adding compounds 10 and 11 under basic conditions would produce compound 9 because the most acidic proton in compound 11 is located on carbon 3. Unlike in previous schemes, where R groups were detached from carbons, we do not need to convert anything to an ether since compound 11 does not contain an alcohol group.



Scheme 5. Implementation of Stork-Danheiser Approach (2). Adding methanol and an acid to compound 9 produces compound 7.



Scheme 6. Detachment of an R group attached to Carbon 3. Adding compounds 10 and 11 under acidic conditions would produce compound 9.

The final products are compounds 3, 5, 8, 10, and 11 (Figure 3). Compounds 5 and 8 are the same molecule.

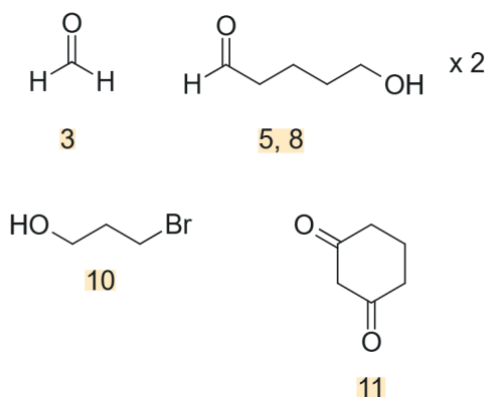
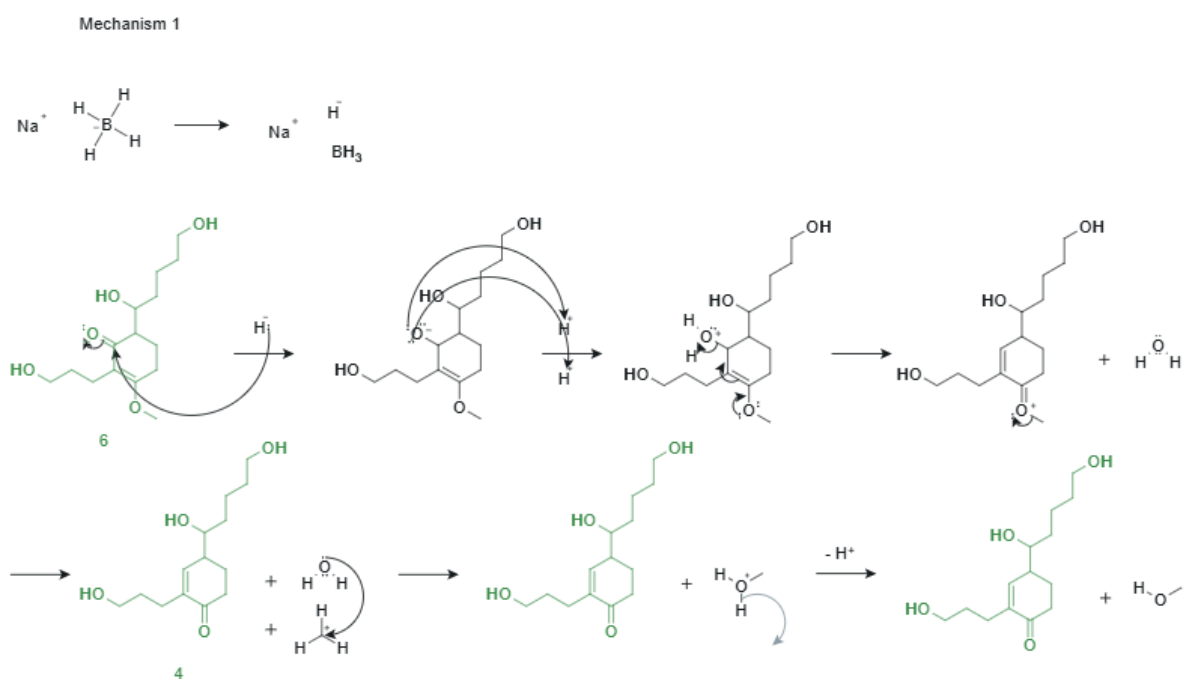
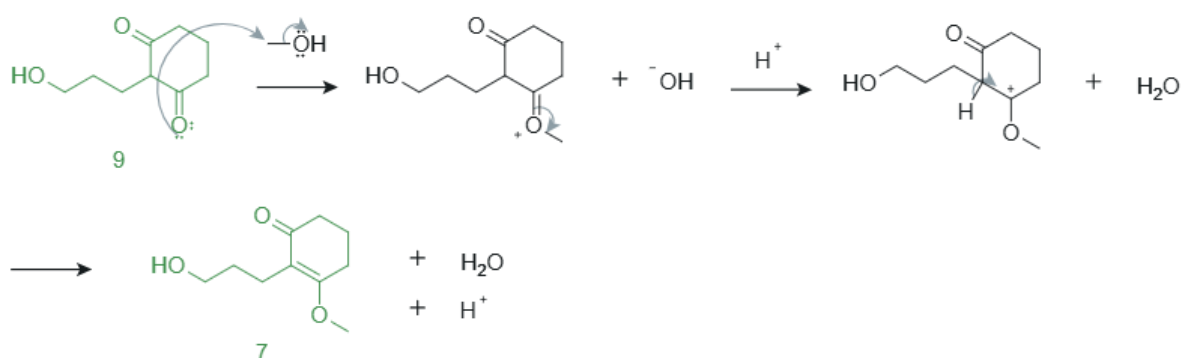


Figure 3. The final products of the retrosynthesis. Using these molecules, along with other readily available compounds such as acids, the target molecule can be synthesized.



Mechanism 1. Depiction of a significant step in the Stork-Danheiser approach, in which compound 6 is converted into compound 4. As depicted above, NaBH_4 is added, and a H^+ workup is done. Methanol is a byproduct.





Mechanism 2. Depiction of another vital step in the Stork-Danheiser approach, in which compound 9 is converted into compound 7. Methanol and an acid are added for synthesis, with water as the byproduct.

Discussion

The proposed retrosynthesis of Ormosianine A is a theoretically feasible retrosynthesis route. By systematically applying oxidation level analysis and breaking carbon-carbon bonds, the complex structure of Ormosianine A was broken down into simpler, commercially available building blocks. Each retrosynthetic step was guided by principles of acidity, protecting group strategy, and reactivity under basic conditions, showing that the forward synthesis in a lab is chemically plausible.

The retention of the olefin in Scheme 1, even though the oxidation level analysis suggested its removal, turns out to be a strategic decision to facilitate later coupling reactions. For example, from a synthetic perspective, when adding compounds 2 and 3 to form compound 1, assuming the alcohol groups are protected as ethers, the methanol group adds to carbon 2 due to the presence of the most acidic proton at that position. However, if the olefin were absent, and an alcohol group were added, carbon 3 would have had the most acidic protons because it is the α -position for both the alcohol and ketone groups (Figure 4). Therefore, the methanol group would add to carbon 3, an undesired consequence.

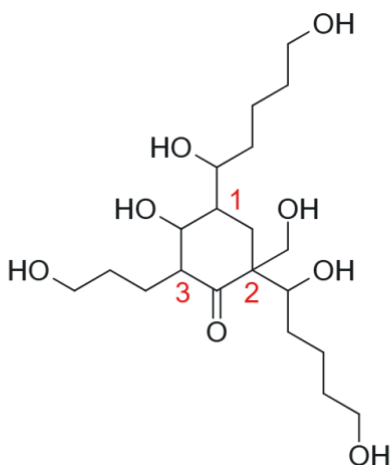


Figure 4. An alternate oxidation level analysis of Ormosianine A. The result of this oxidation level analysis produces undesired consequences, such as the addition of R-groups to undesired carbons.

Moreover, the fact that all final precursors, 3, 5, 8, 10, and 11, are either commercially available or easily synthesizable further supports the practicality of this retrosynthetic route. Furthermore, the repeated application of the Stork–Danheiser strategy reinforces the plausibility of the retrosynthesis, as its experimental conditions are well established and supported by numerous precedents validating the mechanism, thereby enhancing its commercial scalability.

As mentioned above, it would be essential in the synthesis process to protect the alcohol group as an ether. If the alcohol groups are not protected, the precedents with alcohol groups would have protons more acidic than those attached to carbons, so R groups would attach to the oxygen rather than to our desired carbons. For instance, when combining compounds 7 and 8 to synthesize compound 6, if the sole alcohol group in compound 7 is not protected, the butanol group would attach to the oxygen because its hydrogen has the lowest pK_a value.

One potential challenge in the forward synthesis process would be converting compound 1 into Ormosianine A. This is especially concerning because Ormosianine A has nitrogens, even though compound 1 does not have them. Implementing the Mannich reaction would help in this case. The nitrogens can be installed at carbons 1 and 2 as imine intermediates via a Mannich reaction, in which iminium ions formed from an amine and formaldehyde are attacked by the enolizable α -carbons



adjacent to the ketone. These steps form new C–N bonds at C1 and C2 and generate a bis-aminated intermediate, which then undergoes subsequent cyclization and functional group adjustments to produce the final compound.

Overall, the proposed pathway represents a significant step toward the efficient and scalable production of Ormosianine A, which is an efficient AChE inhibitor and thus a highly promising AD medicine. Given the extremely low availability and yield from *Ormosia yunnanensis*, a synthetic alternative is essential for any future pharmacological development of the compound. This retrosynthesis lays the framework for experimental synthesis from simple compounds to our final product.

Conclusion

In conclusion, the proposed pathway represents a significant step toward the efficient and scalable production of Ormosianine A, which is an efficient AChE inhibitor and thus a highly promising AD medicine. Given the extremely low availability and yield from *Ormosia yunnanensis*, a synthetic alternative is essential for any future pharmacological development of the compound. This retrosynthesis lays the framework for experimental synthesis from simple compounds to our final product.

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References

- (1) Anand, P.; Singh, B. A Review on Cholinesterase Inhibitors for Alzheimer's Disease. *Arch. Pharm. Res.* 2013, 36 (4), 375–399. <https://doi.org/10.1007/s12272-013-0036-3>.
- (2) Murray, A. P.; Faraoni, M. B.; Castro, M. J.; Alza, N. P.; Cavallaro, V. Natural AChE Inhibitors from Plants and Their Contribution to Alzheimer's Disease Therapy. *Curr. Neuropharmacol.* 2013, 11 (4), 388–413. <https://doi.org/10.2174/1570159X11311040004>.
- (3) Krátký, M.; Štěpánková, V.; Vorčáková, K.; Švarcová, M.; Vinšová, J. Novel Cholinesterase Inhibitors Based on O-Aromatic N,N-Disubstituted Carbamates and Thiocarbamates. *Molecules* 2016, 21 (2). <https://doi.org/10.3390/molecules21020191>.
- (4) Le, T. T. M.; Pham, H. T.; Trinh, H. T. T.; Tran, H. T.; Chu, H. H. Isolation and Characterization of Novel Huperzine-Producing Endophytic Fungi. *J. Fungi* 2023, 9 (12). <https://doi.org/10.3390/jof9121134>.
- (5) Jin, Q.; Qin, X. J.; Sun, W. J.; Ding, X.; Zhao, Y.; Wang, C. B.; ... Luo, X. D. Ormosianines A–P, Structurally Diverse Quinolizidine Alkaloids with AChE Inhibitory Effects. *J. Nat. Prod.* 2023, 86 (9), 2193–2205. <https://doi.org/10.1021/acs.jnatprod.3c00493>.
- (6) Stork, G.; Danheiser, R. L. Allylic Alcohol Rearrangement to Enones. *J. Org. Chem.* 1973, 38, 1775–1776.

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EVALUATION OF CHINA'S CARBON EMISSION TRADING POLICY SCHEME AND IMPACT ANALYSIS TOWARDS ENTERPRISES TECHNOLOGY INNOVATION

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Abstract

China's economic development, the rapid growth of national industry and manufacturing has resulted in a substantial increase in CO₂ emissions in recent decades. Thus, China's carbon emissions trading policy aims to force relevant enterprises to implement low-carbon technology innovation to address environmental challenges. Our study reviews the agenda-setting, formulation, adoption, implementation, impact analysis, and the logic model evaluation of the carbon emission trading policies. Then, we have got two main conclusions. One conclusion is that the carbon emissions trading policies positively impact the green innovation of enterprises. However, this impact has industries, regions and enterprises' scale heterogeneity. Another is that China's legislation and market mechanisms of the carbon emission trading policies should be strengthened and improved. Based on the above conclusions, some crucial implications are suggested to optimize China's carbon trading policy and green innovation of enterprises.

Key Words

Carbon EmissionTrading Policy, Green Innovation, Enterprises, Logic Model

Introduction

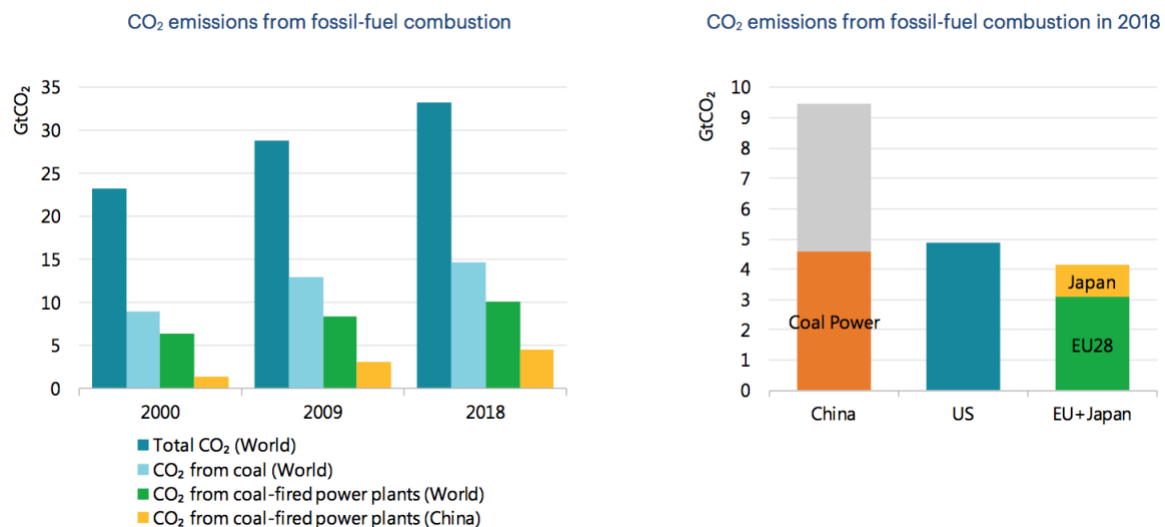
As a globally wide environmental issue, global warming is strongly connected with continuously increasing CO₂ concentration in the atmosphere and affecting the global temperature (IPCC, 2014). Various policies and strategies are launched to control greenhouse gas emissions. One of the popular market-oriented regulation mechanisms is the emission trading scheme (ETS), which has been adopted in the U.S., New Zealand, and the European Union. China is the world's second largest carbon emitter, accounting for 27% of global emissions of carbon dioxide equivalent (CO₂e) (OECD, 2020). Under such circumstances, the China government promised to reach the goal of reaching the peak of CO₂ emission by 2030 and achieve carbon neutrality by 2060. China has implemented carbon trading in pilot areas since 2013 and actively started to establish the national carbon market based on ETS as an environment policy designed within a quasi-experimental framework. This national wide policy generates a wide impact towards national economics, energy industry, and enterprise entities. This paper aims to evaluate China's carbon emission trading policy through policy life cycle including agenda setting, policy formulation, policy adoption, policy implementation and policy evaluation. Firstly, the background of ETS policy will be introduced, and then the QED experiment used in ETS policy formulation stage will be analysed. Thirdly, prior to implementation analysis, the stakeholder analysis framework will be applied, and this paper mainly focuses on enterprise entities and their interest connection with ETS policy based on Porter hypothesis (1995). Next, the policy carrying out phase will be discussed on the basis of data quality and credibility analysis. As for the impact evaluation part, the DID model is applied to test impacts of ETS policy on enterprise innovation based on R&D, patent measurement and regional analysis. Finally, leveraging a logical model conducts policy evaluation and generates policy implication.

Agenda Setting and Policy Formulation



International responsibility and economic transformation are two main driving forces of ETS policy. With rapid development of China's economy, industrialization and urbanization these years, the energy consumption has also increased rapidly. According to IEA (2019), China CO₂ emissions from coal-fired power plants increased between 2000 and 2018 to reach 4.6 GtCO₂ demonstrated in Figure1. In this case, the government People's Republic of China (hereafter, "China") takes its corresponding Nationally Determined Contribution (NDC) to the Paris Agreement on climate change and its long-term low-carbon strategy. The specific climate goals and promises including China's carbon intensity will be reduced by 60% to 65% compared with 2005 by 2030, and the peak will be realized by 2030 at the latest, meanwhile, strive to achieve carbon neutrality by 2060 (IEA, 2019). Another macro context of this policy is China's economy entering a "new normal state", with economic growth rate gradually slowed down and facing resources and environment challenging (Song et al., 2018) and it is necessary to transfer energy construct.

Figure 1: IEA (2019), CO₂ Emissions from Fuel Combustion 2019 and IEA (2019b), World Energy Outlook 2019 for 2018 data



In face of tremendous international community pressure and severe domestic environmental and economic problems, ETS policy is introduced nationwide, aiming to promote the application of market mechanisms and control green gas emission with relatively lower cost. Meanwhile, the government also intended to force enterprises to carry out low carbon technology innovation, which can accelerate the economic development mode transformation (Zhang et al., 2019).

The policy is formulated based on the Quasi-experimental design (QED) framework. QED means, instead of randomly assigning subjects to intervention group and control group, two groups are formulated through various and non-random processes, which is an effective method to determine the impacts of policy or program (Newcomer, Hatry & Wholey, 2015). The carbon trading pilots in China are not randomly selected but are artificially selected according to the observable factors. The city pilots have three phases in total. Firstly, in 2010, the National Development and Reform Commission of China (NDRC) initiated the first low-carbon pilot program, including five provinces (Guangdong, Hubei, Liaoning, Shaanxi, and Yunnan) and eight cities across the country. In the second phase, in 2012, Hainan province and 28 cities were included in the pilot cities. In the third phase, in 2017, 45 more cities were included. Due to the data availability, there are 71 low-carbon pilot cities in the final sample. Compared with the control group, these pilots are mainly concentrated in China's western region and to the right of "Hu line" which divides China geography into two zones with significant diversities in both socioeconomic conditions and natural environment. The outcome indicates the difference between control groups, i.e. cities without low-carbon policy and treatment group, i.e. these pilot cities with low-carbon policy are statistically significant at the 1% confidence level using a two-tailed t-test (Yu & Zhang, 2021). The relevant indicators include labor force, capital input, energy consumption. This result provides evidence that low-carbon city pilot policy plays a vital role in driving carbon mitigation across cities in China. Moreover, the impact of low-carbon policy in the treated cities was 0.017 and the impact

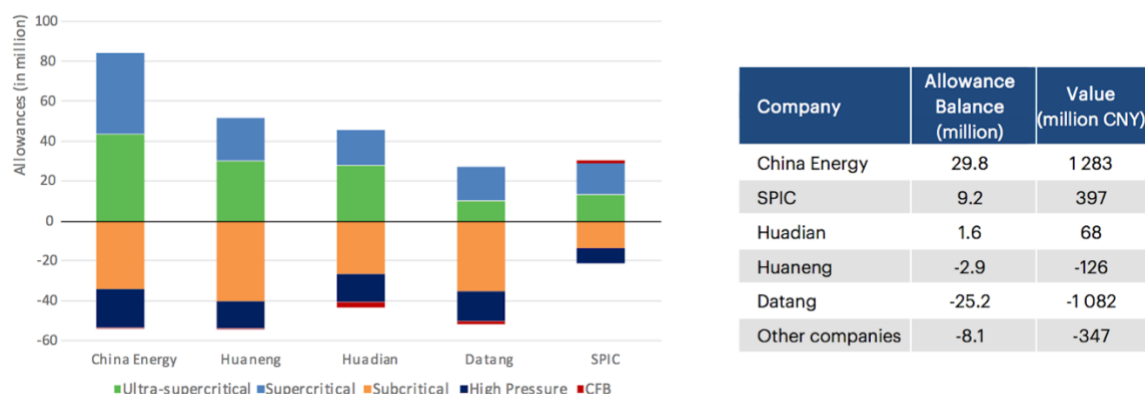


on neighboring untreated cities is about 64% of that on the treated cities (Ibid). This Quasi-experiment provides references for low-carbon strategy and improving carbon emission efficiency and endorsement for ETS introduction.

Enterprise Entities as Key Stakeholder

Stakeholder refers to individual, group or organizations, who can impact or be impacted by a policy evaluation process or its result (Newcomer, Hatry & Wholey, 2015). ETS policy is a way to add carbon prices to leverage market mechanisms. In this market, enterprises, as a major source of green gas emission, are the main entity to transact the emission quota. Thus, the enterprise is a critical stakeholder of ETS policy. As for concentrated industry of enterprise, the power sector and manufacturing, with electricity (40%) and industry (29%) alone making up more than two-thirds of the nation's total greenhouse gases emissions. Additionally, such sectors are dominated by large state-owned enterprises (SOE) in China, for example, 5 biggest SOEs in China power sector including CHN Energy, Huaneng Group, Huadian Group, Datang Corporation and State Power Investment Corporation make up more than half of China's installed coal capacity. Meanwhile, in 2018, these companies produced approximately 2.5GtCO₂ from their planets, which account for more than 50% of China's annual emissions from the entire coal-fired power fleet. According to the IEA report (2021), three of the top five power SOEs could receive an allowance surplus in the Balanced Case, opening the possibility of windfall profits and remaining two companies could face great stringency with a deficit of CNY 36.2 million, as demonstrated in figure 2.

Figure 2: IEA (2019 b), Allowance balance by technology and company in the Balanced Case



However, whether related enterprises are motivated to react in the way which meets the expectation in the policy formulation stage is worthy to be discussed. The key government expectation through ETS policy is to motivate companies to upgrade technology and achieve energy transition. According to Porter Hypothesis (Porter & Linde, 1995), the correlation between environmental policy and enterprise innovation do exist. Innovation offset effect can be generated through reasonable environment policies in terms of enterprises being motivated to conduct innovation activities. Such technology innovation activities improve enterprises competitiveness and productivity, and the social welfare created can make up or even exceed environmental regulation costs. Nevertheless, whether enterprises can benefit from environmental policy largely depends on whether the policy can promote the technology innovations of enterprises, and the effect scale matters. There are three mainstream perspectives. Firstly, environmental policy could obstruct enterprise technology innovation (Carrionflores, Innes, & Sam, 2013) as increasing cost weaken enterprise innovation ability and increase enterprise cash flow stress. Secondly, environmental policies promote the technology innovation of enterprises and increase environmental related patents (Chang & Sam, 2015; He & Shen, 2017; Rubashkina, Galeotti, & Verdolini, 2015). Thirdly, the relationship is uncertain, and the impact could be insignificant (Ibid).

The enterprise, as a significant policy stakeholder, is tied to the policy. If the ETS policy can generate a positive effect, enterprises tend to cooperate and actively participate in this policy, as a result, it can



be implemented to a great extent and be more sustainable, furthermore make policy impact more significant. An evidence-based analysis of policy impact towards enterprise will be discussed later.

Implementation and Data quality

Policy implementation refers to the phase when action is taken to address public problem and High-quality data is critical to the implementation of ETS policy and the continued expansion of policy coverage. At this stage, the policy proposal is implemented by the respective government departments and agencies, in cooperation with other relevant organizations (Newcomer, Hatry & Wholey, 2015). Currently, China's ETS policy has already entered the "Market Operation" implementation phase, which is outlined by National Development and Reform Commission (NDRC) (China Dialogue, 2021). In this stage, the government needs to first decide covered industries, greenhouse gas ranges and thresholds in this carbon transact market, and then set the allowed carbon emission quota of greenhouse gas in every sector. With the total industry quota set, the carbon emission quotas among enterprises needed to be decided by the government, which can be freely transacted between companies. In this mechanism, enterprises need to pay the government a carbon quota equal to actual carbon emission at the end of each trading period.

During the implementation process of the market operation, it is critical for the government to determine the quota and develop a credible CO₂ emission accounting system, both in industry level and enterprise level. Hence, the supporting data source and data quality is of great importance. Since 2011, eight regional emissions trading systems (including Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Hubei, Chongqing and Fujian) were consecutively introduced in different parts of China. These pilots provide supporting data of carbon pricing and the regulation volume of caps based on carbon emissions per unit of GDP. However, China gains enterprise emission data through enterprise self-report, which could lead to more widespread data manipulation when the government lacks monitor funds and expertise. Meanwhile, enterprises may not have full capacity to measure and report data accurately. Considering China's administrative system, local governments need to assemble local companies self-reported emission data and report them to higher level governments. And the data will serve as a basis for higher levels of government to evaluate the performance of lower levels of government (Ghanem and Zhang, 2014). As a result, the reliability of data source could be questionable.

A study (Zhang et al., 2019) compared enterprises' self-report CO₂ emission with emissions verified by third party in Beijing and Hubei pilot emission trading system. The outcome is that the average discrepancy is statistically significant in Beijing, falling from 17% in 2012 to 4% in 2014 and 2015, while statistically insignificant in Wuhan, decreasing from 6% in 2014 to 5% in 2015 (ibid). Currently, the report verification process in Beijing is that each report is rated by three independent experts and the process is fully funded by Beijing government on some occasion to guarantee independence of external monitor. Nevertheless, such pattern is challenging to replicate nationwide in terms of the high financial cost of third-party verification and corresponding high government administrative cost.

Currently, the national carbon market mainly covers power industries with more than 2,000 power generation facilities enlisted thanks to its complete, accurate, standardized basic data (Carbon Brief, 2021). Petrochemical, chemical, building materials, steel, nonferrous metals, paper, aviation and other high-emission industries will be added into carbon trade market subsequently. Moreover, firms' carbon emission data will gradually open to financial institutions as a reference for them to provide financing service and financial derivatives such as carbon futures, options and forward contracts. In conclusion, the reliability and accuracy of current data quality needs to be further improved as the mechanism needed to include more enterprises from various sectors and individuals as trading subjects, and financial carbon products in the future implementation phase.

Impact Evaluation and Data Analysis

Impact evaluation provides information about the impacts produced by an intervention. The ETS policy mainly targets carbon-intensive enterprises in pilot regions. In the impact evaluation part of this paper, we will represent the concept of green innovation by the number of innovation patents and the amount



of R&D investment, respectively, and then measure the impact of ETS on green innovation from both enterprises and regional perspectives.

The difference-in-differences (DID) model can be applied to dividing samples into experimental groups and control groups according to the time and location of the effect, based on which the ETS policy can be evaluated and compared. Years before 2011, namely before the introduction of the policy, are taken as non-pilot years, while those after 2011 are taken as pilot years. In this regard, the experimental group includes enterprises affected by the policy in pilot cities, while the control group includes those from other non-pilot cities and provinces. Therefore, the three studies involved in the following part fall into the Quasi-experimental design (QED). In the DID model, the dependent variables serve as indicators of green innovation, which differ from each other in measuring green innovation. Among the independent variables, the interaction term “TP” is the most important one, which is obtained by multiplying T and Pilot. Before the implementation of the policy, T=0, while after that T=1. If the ETS covers the target enterprises, then Pilot=1, otherwise Pilot=0 (Zhang et al., 2020). TP is applied to show whether the policy is implemented and whether the policy covers relevant enterprises. In addition, different studies tend to contain other different independent variables related to respective purposes.

The data mentioned in the study is panel data in China from 2008 to 2017, covering 456 companies in 8 industries: namely, Steel, Building, Power, Aviation, Petrochemical, Chemical, Nonferrous, and Paper. Specific sources for data include State Intellectual Property Office, Wind database, China Energy Statistical Yearbook, etc.

The effect of ETS on green innovation in patent aspect

In this research, the total number of green innovation patents each year is applied to measuring the enterprises' green innovation. Invention patents are characterized by novelty, creativity, and practical application value, which implies it can be taken as an indicator measuring the innovation capability of enterprises. The independent variables include four elements as follows. TP is used to indicate whether the policy is implemented and covers relevant enterprises. Image shows the logarithm of the number of years after listing enterprises; Poe shows whether an enterprise belongs to state-owned enterprises. If it is, Poe=1, otherwise Poe=0; Lncpl means the logarithm of per capita fixed assets. Model 1, a benchmark model, only contains one independent variable, TP; based on Model 1, Lnage, Poe, and Lncpl are added to Models 2, 3, and 4 (Zhang et al., 2020).

Table 1: The effect of ETS on enterprises' green innovation (patent)

Variable	Model 1	Model 2	Model 3	Model 4
TP	0.0238	0.0213	0.0183	0.0116
Lnage		-0.0975***	-0.1457***	-0.1418***
Poe			0.1543***	0.1611***
Lncpl				-0.0145
Constant	0.6350***	0.8313***	0.8216***	0.8644***
Sector fixed effect	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
R ²	.0260	.0294	.0318	.0317
Observation	3,413	3,413	3,413	3,413

Through Table 1, it can draw the following findings. Firstly, for the most critical variable, TP, its coefficient is valued between 0.011 and 0.025, the p-value is greater than 0.1. It indicates the higher technology innovation in enterprises covered by ETS, which is not statistically significant. In terms of the number of patents, the effect of the policy is not obvious. After implementing the policy, enterprises would try to reduce carbon emissions through measures such as investment adjustment, changes in energy structure, and advanced equipment procurement (Mi et al., 2018). However, such efforts have not significantly improved the level of technology innovation of enterprises. In addition, it has been short since the introduction of China's ETS policy, but it takes quite a long period for enterprises to innovate



their technology (Wicki & Hansen, 2019). In this sense, it is hard for an enterprise to produce a large number of new invention patents in a short time. But conditions may improve over time, leading to more significant results.

Moreover, the listing years of an enterprise and its nature, namely whether it is a state-owned enterprise, tend to greatly impact the green innovation, with p-value less than 0.01. On the one hand, the listing years of an enterprise have a negative relation with green innovation since young enterprises are often more willing to engage in innovation (Atanassov, 2013). On the other hand, the nature of an enterprise, whether it is a state-owned enterprise, significantly impacts green technology innovation. In China, state-owned enterprises are more abundant in the capital and are more subject to policies. Meanwhile, it is easier for them to improve technology innovation through administrative and other means.

Table 2: The effect of ETS on enterprises' green innovation in various industries (patent)

	Steel	Power	Aviation	Chemical	Building	Petrochemical	Nonferrous	Paper
Variable	DID	DID	DID	DID	DID	DID	DID	DID
TP	-0.2109	0.3501**	0.4830***	-0.0948	0.1307	-0.5735	-0.1911	-0.1014
Lnage	0.7804***	-0.3462***	-0.5202**	-0.2399***	0.2489***	-0.5516***	-0.4658***	0.0872
Lnclpl	0.8907***	0.1106***	0.0718	-0.0679	-0.0184	0.3107***	0.4233***	-0.0676
Poe	0.4197	-0.2462**	1.6220**	0.2438***	-0.3394***	1.6774***	1.0274***	0.0053
Constant	-4.4755***	0.5315**	-0.6995*	1.2706***	-0.0639	-0.9396*	-0.0921	0.5294*
Sector fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R ²	.2681	.1595	.2468	.0852	.1098	.5193	.1651	.0566
Observation	253	559	93	1,239	512	106	447	203

Even though ETS exerts a slight impact on enterprises' green innovation, regarding each industry, it shows an influence of industrial heterogeneity. The p-value of TP is less than 0.05 for the Power industry, while less than 0.01 for the Aviation industry, which are statistically significant. In the other six industries, the coefficient of TP is not significant. ETS has significantly improved green innovation in the Power and Aviation industries. In China, the Power industry ranks top 1 for carbon emissions (Wen et al., 2017). In 2020, China reached 1,245 GW regarding the thermal power installed capacity, accounting for more than 60% of the overall installed capacity. The Power industry recorded 37% of the national carbon emissions. In this sense, the Power industry tends to be the number one covered by the ETS policy and suffers the most influence. Relevant policies have imposed tremendous pressure on the Power industry, in which case enterprises in this field have further reduced carbon emissions through technology innovation. Therefore, these enterprises have witnessed enhancement in their technological innovation capabilities. The Aviation industry ranks last in carbon emissions, but it grows at the fastest speed (Nava et al., 2018). Given the low-profit margin of the Aviation industry, the increase in the price of carbon emissions may further squeeze their profit. In this case, the Aviation industry hopes to reduce the cost of carbon emissions while instead striving for innovation in various forms.

The effect of ETS on province green innovation

The second research applies the number of patents to measure green innovation. The difference lies in the changes in the research objects from the original enterprises to the current provinces. A province can be represented by all enterprises in the pilot area covered by the policy. Independent variables also include industrial structure (IS), urbanization level (UR), human capital (HC), energy consumption intensity (EI), which are the control scalars that could affect green innovation at the provincial level (Liu et al., 2022).

Table 3: ETS and green innovation

Variables	Coefficient	t-Statistic
TP	0.0196***	2.8675
IS	0.9742***	3.6003
UR	2.1118***	3.8191
EI	- 0.4014***	- 3.4385
HC	0.3708***	3.3809
Cons.	- 0.0707***	- 6.1718
R-squared	0.6944	

From Table 3, the regression coefficient is 0.0196. The p-value is less than 0.01 for the interaction term, indicating a significant impact of the ETS policy on the green innovation of provinces in the pilot area. In summary, ETS promotes the development of green technology innovation in the entire region, including renewable energy utilization, green technology R&D investment, and construction of a clean energy system, thereby realizing carbon emission reduction. Furthermore, the p-values of IS, UR, HC, and EI are also less than 0.01, implying a significant impact of the ETS policy on the green innovation of provinces. Among them, IS, UR, and HC refer to economic level, knowledge level, and technical level, which all positively impact green innovation. But EI has a significantly negative effect on green innovation.

Table 4 : ETS and green innovation in different regions

Variables	BTIP		SIP		GIP		HCIP	
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
TP	0.0836***	4.9915	- 0.0771***	-3.2592	0.0235	1.1318	-0.0086	-0.7029
Control variables	Control		Control		Control		Control	
R-squared	0.9862		0.9827		0.9780		0.7693	
Time fixed	YES		YES		YES		YES	
Province fixed	YES		YES		YES		YES	

The pilot provinces fall into four regions: Beijing-Tianjin (BTIP), Shanghai (SIP), Guangdong (GIP), and Hubei-Chongqing (HCIP). Among them, the ETS policy has a significantly positive effect on the region of Beijing-Tianjin. Markets in this region are more willing to alleviate pressure from emissions quota constraints through green innovation, which enhances innovation motivation. As for the area of Shanghai, the ETS policy shows a significantly negative effect on green innovation, which can be attributed to two possible reasons. Firstly, in response to the increased cost burden of the ETS policy, enterprises have chosen the reduction in production rather than green innovation, as the latter takes a long time to satisfy results. Secondly, there is the lowest entry threshold of China Registered Emissions Reduction policies in Shanghai, which results in an active carbon trading market in Shanghai (Wen and Xu, 2018). In this context, enterprises are more inclined to buy carbon emission permits than engage in green innovation. The ETS policy reveals an insignificant impact on regions of Guangdong and Hubei-Chongqing, but for different possible reasons. For the area of Guangdong, it has already been the leader in China's green technology innovation. It has achieved the goal of green and sustainable development before the arrival of the policy (Peng et al., 2021). Therefore, the ETS policy does not play a significant role in Guangdong. As for the region of Hubei-Chongqing, it still heavily relies on high-energy-consuming industries. Enterprises in this region tend to take a negative attitude, thus posing obstacles to implementing the policy. In this case, the carbon trading markets face a slack season.

The effect of ETS on green innovation in the R&D investment aspect

In the third study, Liu divided the sample enterprises into three groups, namely, enterprises of pilot industries in pilot provinces (treatment group), enterprises of non-pilot industries in pilot provinces (control group 1), and enterprises in non-pilot provinces (control group 2) (2017). In addition, the element of R&D investment is used to measure enterprises' green innovation. R&D_level indicates the R&D investment intensity, that is, R&D expenditure/total sales revenue*100%. R&D_standard refers to



the standardized R&D intensity, which is obtained after the standardization of the R&D intensity of the industry to which the company belongs. R&D_dummy indicates whether the enterprise engaged in R&D investment that year.

Table 5: The effect of ETS on enterprises' green innovation (R&D investment)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	R&D_level	R&D_level	R&D_standard	R&D_standard	R&D_dummy	R&D_dummy
Cprov×Cindus×Post	0.7801*** (0.2594)	0.6981** (0.2720)	0.0305** (0.0122)	0.0278** (0.0121)	1.0414*** (0.3371)	0.9208** (0.3710)
Cindus×Post	-0.7036*** (0.2105)	-0.6945*** (0.2070)	-0.0030 (0.0064)	-0.0038 (0.0064)	-0.6610*** (0.2250)	-0.6629*** (0.2284)
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	R&D_level	R&D_level	R&D_standard	R&D_standard	R&D_dummy	R&D_dummy
Cprov ×Post	-0.1182 (0.2401)	-0.1251 (0.2300)	-0.0124* (0.0065)	-0.0130** (0.0064)	-0.2628 (0.2394)	-0.2415 (0.2497)
Cprov×Cindus	-0.5683 (0.3460)	-0.6882** (0.2974)	-0.0299*** (0.0087)	-0.0319*** (0.0087)	-0.1860 (0.2578)	-0.2521 (0.2406)
Cindus	-0.7802*** (0.2098)	-0.6066*** (0.2090)	-0.0296*** (0.0047)	-0.0205*** (0.0047)	-0.3069** (0.1369)	-0.3329** (0.1616)
Post	2.2463*** (0.1633)	2.3020*** (0.1734)	-0.0051 (0.0038)	0.0007 (0.0039)	2.1396*** (0.1428)	2.1324*** (0.1485)
Cprov	-0.4881*** (0.1732)	-0.3457** (0.1745)	0.0016 (0.0123)	0.0053 (0.0122)	-0.5602*** (0.0785)	-0.4826*** (0.0804)
Constant	-2.2152*** (0.2860)	-406.6412*** (140.2402)	0.0689*** (0.0084)	-10.2151*** (2.3112)	-1.3885*** (0.2630)	-252.6085*** (81.6652)

Columns 1, 3, and 5 in Table 5 represent the regression results without adding other control variables. Columns 2, 4, and 6 refer to those adding other control variables such as total year-end assets, enterprise net profit rate, and asset-liability ratio. The original interaction term is expanded to include three items in this study; Cprov indicates whether it is a pilot province or city covered by the policy; Cindus indicates whether the enterprise falls into policy-influenced industries; Post means whether the ETS policy pilot covers the enterprise. The estimated coefficient of Cprov×Cindus×Post is significantly positive, indicating that the ETS policy helps promote more R&D investment activities and encourage technology innovation. According to the results in Columns 5 and 6, few enterprises of the treatment group tend to engage in R&D investment before the implementation of the ETS policy, which is opposite to the situation after the arrival of the policy. Therefore, all the empirical results in Table 5 prove that the ETS policy in China has a significantly positive effect on the R&D and innovation of enterprises.

Table 6: Green innovation effect of ETS and enterprises scales

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Large-scale enterprises		Small-scale enterprises			
R&D_level	R&D_standard	R&D_dummy	R&D_level	R&D_standard	R&D_dummy	R&D_level
Cprov×	0.9608**	0.0474***	1.3618**	0.1674	0.0020	0.3969
Cindus×Post	(0.4437)	(0.0150)	(0.5335)	(0.4765)	(0.0191)	(0.4232)
Constant	784.1912 (484.8994)	41.4055*** (11.3003)	282.0550 (495.7238)	-749.5661*** (264.3509)	-21.5210*** (8.1160)	-213.0217 (204.9343)

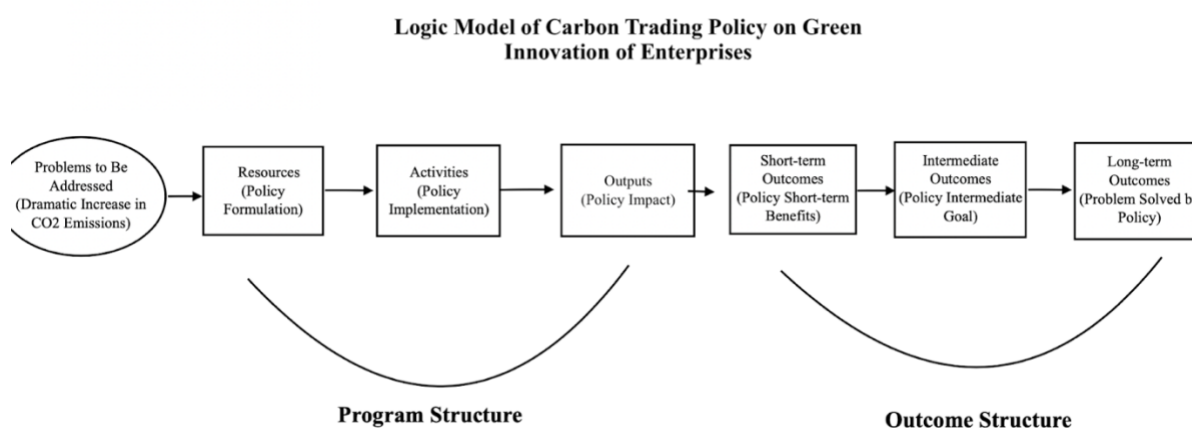
The ETS policy shows the quality of industrial heterogeneity. Since the size of an enterprise may relate to its marginal emission reduction cost, it may further affect its innovation choices under the ETS policy. In this study, those larger than the industry average enterprise-scale companies are considered large-scale enterprises. In contrast, those more minor than the average scale is taken as small-scale



enterprises. From Table 6, it can be drawn that for the large-scale enterprises, their estimated coefficient of the interaction term $C_{prov} \times C_{indus} \times Post$ is significantly positive at the 5% significance level. For small-scale enterprises, the coefficient is positive but not significant. Such a result implies that the ETS policy exerts a positive impact only on the innovation choices of large-scale enterprises, which is not the case for small-scale enterprises.

Policy Evaluation Based on the Logic Model

In evaluating whether carbon trading policies can effectively control carbon dioxide emissions, stimulate green technological innovation, and promote energy use and sustainability enterprises, the logic model, a rational model of how a program will work under certain environmental conditions to solve identified problems, can be used as the basis for China's carbon emissions trading policy performance, telling stakeholders how it is qualified to solve the problem (Newcomer et al., 2015). The elements of the logic model are resources, activities, outputs, short-term outcomes, intermediate outcomes, and long-term outcomes (Newcomer et al., 2015).



As for the resources part, ETS is based on a Quasi-experimental design, with 71 pilot cities selected. The statistically significant result provides evidence for the national carbon accounting system and nationwide policy application. Before the policy was released, many experts conducted research and endorsements, which laid a solid foundation for the formation of the carbon emission trading policy.

For the activity structure in the logic model, we can analyze that the effectiveness of the carbon trading system is insufficient and still needs to be improved during the implementation of carbon trading policies. The Chinese government has issued regulations, documents, implementation rules, and guideline standards based on the National Development and Reform Commission to make carbon trading policy operable implementation (IEA, 2020). However, implementing the carbon trading policy generally faces the problem of weak compulsory and binding. Only a few regions in China have issued decisions with high legal effects. Most regions' regulations on carbon trading are of limited effectiveness, and penalties for non-compliant enterprises are not strong enough to form a sufficient binding force, which brings challenges for law enforcement (Zheng, 2019).

At the same time, during the activity structure we also can see that the supervision and verification system are not well developed. China has set carbon emission measurement, reporting, and compliance registers systems to lay a solid foundation for implementing the carbon trading system (Zheng, 2019). However, China's carbon trading verification system is still in its early stages. Most regions lack well-established supervision institutions, making the system somewhat flawed. The quality and accuracy of data resources is a vital aspect. In the absence of government monitoring, data on carbon emissions may be not accurately self-reported by companies (Zhang et al., 2019). The uncertainty of data quality affects the determination of carbon quota and limits the policy application to more industry, thus reducing the efficiency of policy operation. Moreover, most regions set the total amount of quotas more lenient to reduce the resistance to implementation but no enforcement of control over these unauthorized operations by supervision and verification agencies. Notably, the economic



downturn in 2014-2015 led to a further surplus of carbon quotas, resulting in a significant drop in the price of carbon quotas in 2015, which has a negative impact on the effects of the policy (Zheng, 2019).

Then, for the outputs structure in the logic model, we examine the policy impact on green innovation based on the impact evaluation and data analysis. In summary, the main policy impacts are as follows.

Firstly, the impact of carbon emission trading policy on technological innovation shows significant industry heterogeneity. Notably, implementing the carbon emission trading policy contributed to an increase in technological innovation of 0.35% and 0.48%, respectively, for enterprises in the electric power and aviation industries (Zhang et al., 2020). However, carbon emission trading policy has no significant impact on the technological innovation of enterprises in the steel, chemical, building materials, petrochemical, non-ferrous, and paper industries. This heterogeneity exists between the different sectors of enterprise innovation (Zhang et al., 2020). The reason may be that environmental regulation is associated with environmental industry sectors. More severe association impact is, the stronger willingness to improve technological innovation and reduce costs is.

Secondly, there is a regional heterogeneity of the impact of carbon emission trading policy. The policy in Beijing and Tianjin was found to stimulate green innovation, thus contributing to carbon emission reduction (Liu et al., 2022). However, the carbon emissions trading policy in Shanghai, Guangdong, Hubei and Chongqing does not promote green innovation (Liu et al., 2022). These outputs may facilitate the policy's continuous improvement and targeted implementation, making the nation's carbon emission policy orientation for different regions and areas.

Thirdly, the carbon emission trading policy has a significant positive effect on promoting enterprise' green technology innovation. Implementing the carbon emission trading policy can promote enterprises to carry out more research and development investment activities, encourage enterprise technological innovation, and positively affect research and development of green innovation (Liu et al., 2017). Although the carbon emission trading policy has a significant positive effect on the innovation input of large enterprises, it is not significant on the technological innovation of small and medium enterprises (Liu et al., 2017). The reason should be mainly due to the different marginal abatement costs faced by enterprises of various sizes, leading to different emission reduction strategies under the carbon trading mechanism.

Finally, as for outcome structure in the logic model, short-term policy benefit, intermediate goal, and problem solved by policy, three sequential outcomes are included. Currently, policy significantly impacts the energy and electric power industry and improves carbon emission enterprise performance (Zheng et al., 2021). Secondly, the intermediate outcome is the intermediate outcomes, which are expected to result from the short-term outcomes. The ETS policy will apply to seven more industries and allow individuals to enter the carbon trading market. Meanwhile, achieve financialization of China's carbon trading market and transfer mechanism from "output-based" to "volume-based" with more reliable data access. The long-run outcome, as a solution to the environment and economics transformation challenge, ETS policy will promote enterprise green innovation and energy transition. Moreover, as a supportive policy, it enables the realization of reaching the peak of CO₂ emissions by 2030 and achieving carbon neutrality by 2060.

Conclusions

Over the past decades, the rapid development of the national industry and manufacturing (such as steel, coal, petrochemical, and power industries), stimulated by China's economic growth, has led to a dramatic increase in CO₂ emissions. To address the issue, China successfully implements the carbon trading policy, typically representative of China's environmental regulation policy. This paper reviews the agenda-setting, formulation, adoption, implementation, impact analysis, and the logic model evaluation of the carbon emission trading policies. Based on the above review, we have got two main conclusions.

Firstly, the carbon emissions trading policies have a positive impact on the green innovation of enterprises. However, this impact has industries, regions and enterprises' scale heterogeneity. Specifically, the carbon emissions trading policy has a more significant positive impact on enterprises



on aviation and energy industries, in Beijing and Tianjin, and for large enterprises than medium and small companies.

Secondly, China's legislation and market mechanisms of the carbon emission trading policies should be strengthened and improved. China's carbon trading policy has achieved remarkable output on the green innovation of enterprises. However, the market mechanism is imperfect, the law is not well-established, and the supervision and verification system is not mature enough. If these problems are not resolved in time, the primary data will not be accurate enough, which will result in unreasonable quotas and carbon prices of enterprises.

Policy Implications

Based on the above two conclusions, some crucial implications are suggested to optimize China's carbon trading policy and green innovation of enterprises. For the industries heterogeneity, the government should consider the different characteristics of each industry and avoid only one principle for all sectors while promoting emissions trading. The carbon trading policy of the Chinese government should focus on the aviation and the power industry as much as possible, which could stimulate the innovation potential of aviation and power companies and fully utilize the advantages of carbon emission trading policies (Zhang et al., 2020). At the same time, enterprises also need to actively participate in the carbon trading market according to the characteristics of enterprises themselves, further promoting their transformation and enhancing the competitiveness in their industry.

Regional heterogeneity suggests that regions' economic development, human capital, and innovation differences must be fully considered when establishing carbon emission trading policies (Liu et al., 2022). More efficient resource allocation is needed to benefit all areas from the carbon emission trading policy and receive higher green innovation overall, avoiding the imbalance of carbon markets. Thus, the government should implement different carbon emission trading policies based on local conditions.

As for the enterprises' scale heterogeneity, the government should provide more financial support and design more incentives for research and development on green innovation, such as tax refunds, environmental subsidies, low-carbon intellectual property protection, and low-carbon financing systems, particularly for medium and small enterprises (Dou, 2017).

Meanwhile, there is a need to accelerate legislation for China's carbon emission trading market. China needs to reasonably set the access conditions for the carbon emission trading market, improve market mechanisms on supervision and verification, enhance the effectiveness of the implementation of carbon emission trading policy, and form a unified national carbon emission trading system. The government also should take advantage of the policy tools of the carbon trading system, such as carbon emission caps and carbon prices, to guide enterprises to invest in low-carbon technologies (Chen, 2021). In addition, the quotas should be adjusted according to the development stage of enterprises.

In summary, to achieve the realization of reaching the peak of CO₂ emissions by 2030 and achieving carbon neutrality by 2060. The Chinese government should scientifically design and establish a unified, efficient, standardized, and supervised carbon emissions trading system based on the experience of the pilot areas and provide clear policy guidance as soon as possible.

References

- Atanassov, J. (2013). Do hostile takeovers stifle innovation? Evidence from antitakeover legislation and corporate patenting. *The Journal of Finance*, 68(3), 1097-1131.
- Chen, & Lin, B. (2021). Towards carbon neutrality by implementing a carbon emissions trading scheme: Policy evaluation in China. *Energy Policy*, 157, 112510–. <https://doi.org/10.1016/j.enpol.2021.112510>
- DiNardo, J. (2010). Natural experiments and quasi-natural experiments. In *Microeconometrics* (pp. 139-153). Palgrave Macmillan, London.



Dou, X. (2017). Low Carbon Technology Innovation, Carbon Emissions Trading and Relevant Policy Support for China's Low Carbon Economy Development. *International Journal of Energy Economics and Policy*, 7(2), 172–184.

Ghanem, D., & Zhang, J. (2014). 'Effortless Perfection:' Do Chinese cities manipulate air pollution data?. *Journal of Environmental Economics and Management*, 68(2), 203-225.

IEA (2020), China's Emissions Trading Scheme, IEA, Paris <https://www.iea.org/reports/chinas-emissions-trading-scheme>

IPCC, (2014). Climate change 2014. synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). IPCC.

Liu, & Zhang. (2017). China's carbon emission trading policy scheme and Corporate R&D Innovation - An Empirical Study Based on Triple Difference Model. *Economic Science*, (3), 102-114.

Liu, Y., Liu, S., Shao, X., & He, Y. (2022). Policy spillover effect and action mechanism for environmental rights trading on green innovation: Evidence from China's carbon emissions trading policy. *Renewable and Sustainable Energy Reviews*, 153, 111779.

Mi, Z., Meng, J., Green, F., Coffman, D. M., & Guan, D. (2018). China's "exported carbon" peak: patterns, drivers, and implications. *Geophysical Research Letters*, 45(9), 4309-4318.

Nava, C. R., Meleo, L., Cassetta, E., & Morelli, G. (2018). The impact of the EU-ETS on the aviation sector: Competitive effects of abatement efforts by airlines. *Transportation Research Part A: Policy and Practice*, 113, 20-34.

Newcomer, K. E., Hatry, H. P., & Wholey, J. S. (2015). Handbook of practical program evaluation. John Wiley & Sons.

Peng, W., Yin, Y., Kuang, C., Wen, Z., & Kuang, J. (2021). Spatial spillover effect of green innovation on economic development quality in China: Evidence from a panel data of 270 prefecture-level and above cities. *Sustainable Cities and Society*, 69, 102863.

Wen, Z. G., Di, J. H., Yu, X. W., & Zhang, X. (2017). Analyses of CO₂ mitigation roadmap in China's power industry: Using a Backcasting Model. *Applied energy*, 205, 644-653.

Weng, Q., & Xu, H. (2018). A review of China's carbon trading market. *Renewable and Sustainable Energy Reviews*, 91, 613-619.

Wicki, S., & Hansen, E. G. (2019). Green technology innovation: Anatomy of exploration processes from a learning perspective. *Business Strategy and the Environment*, 28(6), 970-988.

Yu, Y., & Zhang, N. (2021). Low-carbon city pilot and carbon emission efficiency: Quasi-experimental evidence from China. *Energy Economics*, 96, 105125.

Zhang, D., Zhang, Q., Qi, S., Huang, J., Karplus, V. J., & Zhang, X. (2019). Integrity of firms' emissions reporting in China's early carbon markets. *Nature Climate Change*, 9(2), 164-169.

Zhang, Y. J., Shi, W., & Jiang, L. (2020). Does China's carbon emissions trading policy improve the technology innovation of relevant enterprises?. *Business Strategy and the Environment*, 29(3), 872-885.

Zheng, S. (2019). Study on subject matters of carbon market. China Economic Publishing House.



Zheng, Y., Sun, X., Zhang, C., Wang, D., & Mao, J. (2021). Can Emission Trading Scheme Improve Carbon Emission Performance? Evidence From China. *Frontiers in Energy Research*, 552.



The Impact Of The U.S. Trade Policy On International Trade Law: Unilateral Tariffs And Paralysis Of The Appellate Body

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Abstract

A growing global crisis are tariff rates and the appellate body of the international trading system. As President Trump entered his second-term, the United States is experiencing the sudden changes in the trading system, initiated by its policies. International trade law follows the foundational principles of the World Trade Organization, but there happens to be a retaliation against the organization, creating a fragmentation in the system. Not only are tariffs weakening the trading system, but the undermining of the dispute settlement further damages international trade relations. The growing concern is the lack of presence in the appellate body which is leading to unresolved and neglected disputes. Without the appellate body, the trading system is completely broken, causing states to divert from the original international trade law.

Keywords

World Trade Organization (WTO); General Agreement on Tariffs and Trade (GATT); Tariffs; Dispute Settlement Understanding (DSU); Appellate Body

Introduction

President Trump proposed to restore America from devastating losses, but a growing body of scholars are arguing the opposite. He vowed to help the country and make it thrive, but instead he is creating fragmentation in the country's credibility and the international dispute settlement system. His viewpoint from the first and second terms aligns as he continues to focus on the importance of increasing tariffs for the benefit of improving the demand of domestic products while reducing the increasing trade deficits. He deems the irrelevance of the World Trade Organization (WTO) and the Appellate Body, as he continues to neglect it, leading to a complete breakdown of the mechanism. He asserts his power by undermining the international legal system and through the creation of tariffs to prove a point, but his main motive for these proposals are unestablished and polar opposite to his liking.

This paper argues that the United States' sustained political strategy of undermining the WTO dispute settlement—through the paralysis of the Appellate Body—has enabled a shift toward unilateral tariff measures that are often defended through GATT (General Agreement on Tariffs and Trade) Articles XX and XXI but, in practice, frequently lack the evidentiary basis required by those exceptions, leaving the measures legally vulnerable and the resulting disputes largely unresolved. The paper is institutionally organized in subsequent sections that will review the course of tariffs and the Appellate Body, WTO's primary dispute settlement system. It will first establish the research question through a literature review that will provide various scholarly perspectives while identifying the gaps between the two topics. Then the paper presents a series of hypotheses that will be tested later in the paper regarding tariffs with the international trade law and the WTO dispute settlement focusing on the Appellate Body. A legal analysis will be presented displaying articles of the GATT with foundational principles of trade and the Dispute Settlement Understanding of the WTO. This will then be followed by case studies that will evaluate the



hypotheses and the paper will display recommendations for international trade tariffs and the Appellate Body, with the results from the case studies. The concluding segment will reflect on the occurring problems in the present day and the analysis of its implications.

Literature Review

A. Introduction

The World Trade Organization (WTO) is the foundation of the global trade system; however, President Trump's administration developed tariffs that dismantled the pillars of international trade law and violated the country's agreed obligations. Over time, the United States administration also refused to appoint new members to the Appellate Body, the WTO's essential dispute settlement system, ultimately leaving it paralyzed and inactive. These violations of international law have been widely criticized by scholars and observers, as they raise concerns about the effectiveness of the organization's legal system and global dispute settlement mechanism.

i. Tariffs

When trading or shipping manufactured goods, tariffs are implemented which are taxes on imported items. The action of implementation, at negotiated rate, is part of the World Trade Organization principles to ensure equality between countries, transparency, stability, and predictability in the international trading system. By focusing on the key aspects of the WTO principles there would be balance and the establishment of an "ideal" trading system ensuring economic opportunities within countries. Importantly, the term "Most-favored-nation" (MFN) is the pillar of the trading system in the matter of tariffs because it pushes on the concept of equal treatment on "like products" trade barriers (General Agreement on Tariffs and Trade 1947, Art 1). These obligations and standards in the WTO present what the countries are expected to follow. International trade laws and tariffs are existing mechanisms in the government to help the foundations of businesses for countries.

ii. Appellate Body

The WTO not only administers their standard principles such as tariffs imposed on imported goods, but also the international disputes that occur as a result of non-compliance with their legal boundaries. The Dispute Settlement Understanding (DSU), establishes the legal frameworks for the mechanism and emphasizes that the Appellate Body, the supreme court of international trade and a central pillar for WTO's dispute resolution system, provides "security and predictability to the multilateral trading system" (World Trade Organization 1994, Art. 3.2). The structured legal process of dispute settlement begins with consultations, panel establishment by a member, followed by appellate review by the Appellate body and the adjudication is finally enforced by the Dispute Settlement Body (DSB). As of 2024, out of 376 times that a panel had been established, 195 disputes were adjudicated by the Appellate Body, indicating its profound role in resolving international legal conflicts (World Trade Organization 2024, par. 8). However, the current paralysis of the Appellate Body has created a legal deadlock, where disputes can still be raised and reports can be issued, but the rulings cannot be finalized. The DSU attempts to mitigate the major flaws in the system through higher emphasis on consultation and mediation, however these non-binding steps are not as influential and imposing as the traditional Appellate Body, indicating the evident limitation in the system.

B. Scholarly Review



Amidst the critical period, in which President Trump's imposition of tariffs infringes the basic WTO legal boundaries, the Appellate Body should have acted according to rigid and consistent policies to bring justice. Instead, the once supreme authority is only left to painfully watch the violation without being able to intervene, and their absence is leaving a profound mark in international relations. Sherman and Joseph outlines this exact circumstance in their article regarding the crisis as they observed China's response to President Trump's 10% increase in border taxes for Chinese goods (Sherman and Josephs 2025). After being controversially charged with being related to illegal pharmaceutical distribution, China filed their complaint, strongly denying the accusation of its role in the fentanyl trade. China protested to the WTO, arguing that the measures taken by the Trump administration were discriminatory and a violation of trade rules. However, many WTO officials have concluded that their dispute has "no possibility of succeeding" as the appellate body remains unable to function due to the U.S.' refusal to approve new appointments of judges (Sherman and Josephs 2025, par. 4).

The authors argued that while the content and the evidence of the case may be valid, without the Appellate Body's underlying adjudicative power to impose consequences and process legal disputes, China's litigation will not be binding. In other words, the United States will be able to get away with a false accusation that potentially defamed a country without receiving appropriate punishment for their wrongdoings. The article demonstrates the evident challenges that occur in the modern world with the absence of the WTO's Appellate Body and how the absence led to a period of international stagnation in legalized trade disputes. Overall, the paralysis of the Appellate Body exhibits the failure of WTO as global relations are tarnished due to the inability to negotiate and settle disputes in a smooth and just manner.

C. Tariffs

The General Agreement on Tariffs and Trade (GATT 1947) established the rules and regulations of the international trading system. The agreement provides clarity on what is expected of countries, defining the accepted actions and restrictions; importantly, it was created to foster unity and prevent the imposition of trade barriers while increasing the likelihood of a stable trading system. The general agreement was to bring prosperity while being advantageous to the concept of "reduction of tariffs and other barriers to trade and to the elimination of discriminatory treatment in international commerce." (World Trade Organization). The "Principles of the trading system" is the general legal trade framework because it provides an outline of the essential aspects of trade, such as the "Most-favored-nation" (MFN) equality principle. The WTO and its principles are contributing to developments and economic reforms to provide opportunities for countries.

These principles are standards countries must follow to ensure a "smooth" distribution of trade. Madeline Sesti wrote an article, "Background on the WTO and recent international trade", to explain the roles of the WTO, along with what the countries have at stake by being a part of this organization. "To achieve such goals, the WTO provides a structured set of rules, mediates disputes, and fosters negotiations among countries." (Sesti 2025, para. 2). The article outlines what the WTO is about and the mechanisms incorporated in the organization to maintain the multilateral trade system. The organization established these obligations to ensure a balanced, stable trading system that allows WTO members to receive benefits. According to Goktug Keskin article "Trade Wars and the WTO: Navigating Trump's 2020 Tariffs", it has pointed out the "reimplementation of aggressive tariff policies significantly disrupted the global trade landscape." (Keskin 2025, para. 1). The president's "good deed" tariffs is questioning the existence and implications of the international trade law system in the matter of the action violation and the future of the trading system.

In Pam Karland and Alan Sykes's podcast transcript "Trade Wars, Economic Chaos, and Law: Unpacking Trump's Trade Tactics with Alan Sykes", it outlines how Trump's tariffs are not following his desire for a "bilateral deficit" since he refuses to follow the standard procedures. Not only are the tariffs and trading system not fully functional, but Sykes also points out that this constant change is a "real problem with the



credibility of the United States has been significantly damaged.” (Karland and Sykes 2025). The podcast references all the questioned topics regarding the president’s actions, which showcases similarities to how Trump is taking the trading system back to the 19th Century. Ryan Mulholland’s article “Why is Trump Pursuing a 19th Century Trade and Economic Agenda in the 21st Century?” reports how the president’s tactics are similar to those of the Gilded Age and how this tariff policy poses threats to the U.S. The scholars Karland, Sykes, and Mulholland agree that Trump’s tariff tactics are only pushing the country into a vulnerable state while concentrating on the idea that tariffs will create problems in the future, as seen in history.

Scholars are focusing on questions about the WTO’s powers and how international trade law is affected as they argue the U.S. position with the organization. Nicolas Lamp wrote an article, “What President Trump’s ‘Reciprocal’ Tariffs Mean for International (Trade) Law,” to argue that international trade laws are no longer incorporated since the US domestic laws are taking over the structure of trading. “People interested in understanding US trade relations have found this WTO law expertise virtually useless” (Lamp 2025, para. 7). Lamp focuses on the aspect of how the US is challenging the trading system by refusal and violations in the WTO, risking predictability and security. He proposes that other WTO members must maintain and respect their obligations to preserve relationships and mitigate the effects of the U.S.’s abandonment of the WTO. Additionally, James Bacchus wrote “Do World Trade Organization Laws Still Exist?” to analyze the WTO’s relationship with the US regarding obligations and rights. Bacchus is arguing that under President Biden’s administration the US had rarely mentioned WTO obligations leading to the idea of “WTO is no longer central to world trade, and that lowering tariff and other barriers to world trade is no longer a principal of U.S. trade policy.” (Bacchus 2025, para. 6). Bacchus and Lamp are agreeing on the arguments of the inexistence of the international trade laws as the U.S. fails to oblige with their agreement further illustrating the image of the U.S. only following rules established within the U.S. Sesti’s article touches on the WTO’s powers, but notes that “the WTO’s ability to enforce its rulings has been significantly weakened in recent years due to the breakdown of its appellate body” (Sesti 2025, para. 6). All the scholars’ arguments collapse with one another leading to the broad interpretation of how the WTO has weakened in abilities and further demonstrates the legal aspects of how international trade law has changed leaving the future uncertain.

D. Appellate Body

The World Trade Organization (WTO) and the Appellate Body, acting as the organization’s supreme court, was a dominant force and were highly effective in carrying out international legal dispute systems in 1995, when they were first established. However, as foreign relations expanded rapidly and more frictional disputes occurred as a result, evident cracks began to appear in the once concrete system of the WTO and the United States were not hesitant in filing complaints regarding the issues.

In Hillman’s article “A Reset of the World Trade Organization’s Appellate Body“, she concisely summarizes the six concerns that the United States had about the way WTO were processing the disputes (Hillman 2020). Their complaints consisted of certain crucial structural errors such as expired WTO members continuing to serve and adjudicate, the system’s common failure to complete appeals in ninety days, excessive overrulings of dispute due to irrelevant obsession on the factual findings, WTO’s secretariats and the developing country benefits. However, the majority of the WTO members expressed “degrees of skepticism about the United States’ concerns” and ultimately their proposals were not completely enforced, marking the beginning of growing tensions between the United States and the WTO (Hillman 2020, par. 8).

This strained relationship did not remain merely within the institution, but soon translated into broader global tensions. The U.S. began violating core policies implemented by the WTO and Stewart’s report explores the negotiation between China and their claim of retaliation rights for the United States’ non-compliance with the Appellate Body’s obligations. The WTO eventually ruled in China’s favor, granting rights for 645 million dollars of yearly trade sanctions, which was legally enforced by the Appellate Body (Stewart 2022,



par. 2). Following this decision, Adam Hodge, a spokesperson from the United States Trade Representative (USTR), argued that the “decision reflects erroneous Appellate Body interpretations” as it fails to protect U.S.’ businesses from “China’s trade-distorting subsidies”(Stewart 2022, par. 4). Through the argument surrounding the controversial ruling, Stewart illustrates the contrasting perspectives between the U.S. and WTO as the government’s confidence and trust in the Appellate Body declines continuously as a result of disagreements in the result of dispute settlements. Overall, the persistent legal disagreements between the United States and WTO Appellate Body have contributed to the broader dispute settlement crisis and ultimately led to the complete paralysis and breakdown of the system, leaving the international trade industry extremely vulnerable to internal conflicts.

This increasing friction between the United States and the organization has prompted many scholarly analysis and debates, examining the core aspect that drove frustration. In a policy column, economists Henrik Horn and Petros Mavroidis argue the reason why the U.S. is dissatisfied with the Appellate Body and decided to dismantle it “did not concern the law itself” (Horn and Mavroidis 2025, par. 3). In fact, they claimed that the frustration stemmed from the number of disputes regarding their policies such as tariffs and anti-dumping measures that were adjudicated against them by the WTO panels.

i. Scholarly Recommendations

In response to the current crisis, there have been several suggested proposals, most notably the Multiparty Interim Appeal Arbitration Arrangement (MPIA), from national governments and individual scholars have evaluated the solution. Hopewell’s policy paper that overviews the breakdown of the Appellate body addresses the MPIA and acknowledges its purpose of preserving the minimal legal procedure and authority over the world. However, she expresses her concerns that with only “32 per cent of the WTO’s membership” and lacking many important states such as India, Russia, South Korea and the U.S., the system requires a more complete set of states to essentially replace the Appellate Body (Hopewell 2025, 1109). She further notes that despite the common occurrence of trade-distorting measures in recent times, such as imposition of tariffs by the U.S. government, the number of disputes in WTO has “fallen to about 40 per cent of the normal level” prior to the collapse of the system (Hopewell 2025, 1113). Through this, she suggests that what was once the world’s most impenetrable dispute settlement system in the world has lost its command over states and requires urgent rescue through a more pragmatic and permanent solution.

Alongside Hopewell, Horn and Mavroidis again argue that the MPIA is not the most suitable solution and they blame the single entity and the root of the crisis, the United States. They stated that if the “US favours a toothless WTO” and are willing to violate fundamental principles, their withdrawal from the WTO may be the least damaging option for preserving the institution’s remaining credibility (Horn and Mavroidis 2025, par. 1).

E. Conclusion

The World Trade Organization in the current trading circumstances is facing hardships from the actions of President Trump. The questions of tariff violations, future of the WTO, consequences of the Appellate Body breakdown, and what could be done for the future are what are trying to be found. Scholars have argued on the points of how the distance between the U.S and the WTO have created a growing amount of unresolved circumstances leading to the uncertainty of the future despite suggested proposals. The sources breakdown the key aspects of the trading system, principles, and necessary details for trade policy; however, how do these agreement of arguments determine the actions of what can be done to restore and maintain the international trade law.



Methodology and Statement of Hypotheses

Hypothesis 1: Rise in Trade–Distorting Measures Hypothesis

The breakdown of the WTO Appellate Body has led to an increase in trade tariffs and the emergence of retaliatory trade measures between the United States and China. The dispute settlement system is designed to mediate conflicts between states through negotiation and legalized procedures to arrive at mutually agreeable solutions. This hypothesis predicts that in the absence of a methodical dispute resolution mechanism, countries are more likely to resort to countermeasures, involving excessive increases in tariffs and other retaliatory trade penalties. The United States and China both encompass the capacity to inflict substantial harm on each other's economies through import restrictions, and measures such as tariffs and trade sanctions become a logical and effective option in the absence of a formal dispute settlement.

Hypothesis 2: Deterrence of Dispute Resolution Hypothesis

The immobilization of the WTO Appellate Body constrains the organization's ability to resolve trade disputes between the United States and China. The WTO dispute settlement mechanism has benefited both the United States and China over multiple decades, resolving disputes through a structured, rules-based forum to ensure compliance. This hypothesis posits that the paralysis of the Appellate Body deters both the United States and China from pursuing formal dispute settlement, as panel rulings are no longer binding and thus no legal proposal or adjudication is made. In the absence of a credible enforcement mechanism, states may perceive WTO litigation as ineffective or irrelevant, leading to a decline in the credibility or usage of the dispute settlement system. Consequently, unresolved trade disagreements persist or are addressed through unilateral or informal means, weakening the role of the WTO as a central forum for managing bilateral trade conflicts.

Hypothesis 3: Null Hypothesis

The international relationship between the United States and China has not been impacted by the paralysis of the WTO Appellate Body. While the WTO Appellate Body does exert profound influence globally, the United States and China have always had the tendency to act independently, being the two dominant forces of the world. This hypothesis suggests that the breakdown of the WTO Appellate Body will not alter the two nations' international relationship in any relevant way, as even when the organization was active, they sometimes ignored or resisted the rulings. While their reliance on the legal adjudication is evident, both the U.S. and China are more than capable of acting independently through other diplomatic measures to settle disagreements between them, ultimately not being severely affected by the paralysis of the WTO Appellate Body.

Hypothesis 4: WTO Article Agreement Violation Hypothesis

President Trump's tariffs violate the WTO (World Trade Organization) agreement, specifically the GATT (General Agreement on Tariffs and Trade) articles.

i. Hypothesis 4a: They violate the Most-Favored- Nation Treatment.

The WTO principle structures global trade to ensure non-discrimination, meaning every country participating in trade must be treated equally, unless a granted favor. This hypothesis section predicts that President Trump's tariffs do not align with the WTO's MFN policy, which allows countries to have equal low trade barriers. Under the GATT, this is a current violation of Article 1: General Most-Favoured-Nation Treatment. President Trump's tariffs do not align with equality or the concept of non-discriminatory trade barriers.



ii. Hypothesis 4b: They violate the Schedule of Concessions.

Another significant WTO principle that structures global trade is the importance of a country maintaining the tariff rates it has agreed to during negotiations, meaning agreed tariff rates preserve non-discrimination and stability in the trading system. The following hypothesis section predicts that President Trump's implemented tariffs violate not keeping the agreed-upon tariff rates on imported goods.. The President's actions violate GATT Article 2: Schedule of Concessions.

Hypothesis 5: No Relationship Between WTO and Tariff

This hypothesis claims that the WTO agreements do not apply to President Trump's tariffs because his particular tariffs are considered to be unilateral actions. President Trump's tariffs were imposed due to his subjective viewpoints on the United States's position with international trade and competition. The WTO agreements are based on prior commitments and negotiations, these unilateral tariffs were based on the President's proposition alongside his will to bring justice to the unfairness of previous trading contradictions. The WTO is not applicable due to the U.S. sovereign move on their trading policies and tariff rates which leads to independence on their intuitive decisions.

Hypothesis 6: Permitted Tariffs Under Exception Hypothesis

While Trump's tariffs appear to violate WTO rules, they are actually allowable under the national security exception to WTO rules.

While President Trump's nationwide tariffs appear to be in violation of the WTO principles, Article XXI: Security Exceptions under the GATT proves the President's actions to be legal. The particular hypothesis argues that national security and the protection of the country are reasonable reasons for the imposition of tariffs. When President Trump announced his proposal, he announced that tariffs were implemented due to the country being in a "national emergency" in the matter of security and the economy. Announcing an emergency and stating the security purposes allows members of the WTO to bypass the initial trade rules making the President's actions legal.

Legal Analysis

The Dispute Settlement Understanding, the WTO Appellate Body and its legal vulnerability

i. The Structure and Legal Procedure of the Dispute Settlement System

Under the Dispute Settlement Understanding (DSU) by the WTO, disputes are resolved in a rigid legal procedure involving many critical steps. The complex process is all initiated with a filed dispute from a state, after a breach in the international laws is anticipated. If the sixty days of consultation and nation-wide negotiation is unable to resolve the case, a panel is established, weighing the arguments from both sides of the argument and the adjudication is delivered (World Trade Organization 1994, Art. 8.1). This deliberately structured and intricate procedure ensures global order when disputes between even powerful states arise, legitimizing conflicts into official negotiations.

The DSU further introduces the Dispute Settlement Body (DSB) as the institutional body responsible for the administration of the DSU. In article 2.1, it specifies the body's institutional duty to "maintain surveillance of implementation of rulings and recommendations" (World Trade Organization 1994, Art. 2.1). This delegation of responsibility to a separate institution emphasizes the importance of the rigid legal procedure as it becomes the fundamental pedestal of resolving all major international diplomatic conflicts.



ii. Formation of the Appellate Body

The legal agreement further outlines the goal of the Appellate Body and the required circumstances to involve the Appellate Body in a dispute. Acting as the supreme court, when a party appeals the adjudication from the panel and does not adopt the decision, then by the DSB, “a standing Appellate body shall be established” (World Trade Organization 1994, Art. 17.1). By assigning distinct conditions that are required to be met, the DSU models the Appellate Body as a strictly law-bound organ that is involved in major international disputes, implying institutional gravity and authority.

The Appellate Body consists of seven individuals of recognized academic achievements, and expertise in law. In addition, the DSU states that the quorum of three selected judges among the distinguished body will serve on the appealed cases in rotation within the four-year term. This quorum requirement is profoundly significant as it allows flexibility and impartiality among the Appellate Body through reinforcing continuous changes of the judges.

iii. Appointment of Judges

When the period of service for judges of the Appellate Body expires, then the vacant positions will be replaced by formal appointments of new qualified judges by the DSB. However, the DSU provides additional requirements for this procedure, stating that when the DSB and close committee finalizes the appointment, it will be presented to the WTO members, and a “consensus” is required, meaning all members of the WTO must agree with the appointment (World Trade Organization 1994, Art. 2.4).

The consensus requirement, on one hand, ensures that appointments reflect the collective agreement of the entire WTO organization and contributes to the reinforcement of the legitimacy and credibility of the Appellate Body judges.

iv. Legal Ambiguity and Area for Reform

However, the exact aspect of the DSU that is intended to validate the Appellate Body has led to its overall decline in credibility and the legal gridlock of the WTO. While the requirement of consensus reinforces equity between states, there is an evident legal ambiguity that exists regarding the ability to reject the judge appointment. The DSU is unable to limit a state’s ability to veto an appointment, and instead allows a state of the WTO to continuously reject the appointment of new members, essentially leaving the possibility of institutional paralysis. This gridlock can have further political implications as it reshapes the bargaining power dynamics during the consultations stage, potentially allowing more powerful and influential countries such as the U.S. to abuse the international system. Indeed, from 2020, the U.S. has effectively avoided nine out of eleven cases where its legal violations would have most likely led to serious consequences otherwise, by appealing the case into “the void”, illustrating how the absence of the system disproportionately benefited different states (Hopewell 2025, 1104).

Even as it argues to fill vacancies “as they arise”, the DSU has been generally discussed among scholars to lack the explanation and secondary solution regarding how the breakdown can be halted, or how the organization could be revived to achieve international justice again (World Trade Organization 1994, Art. 17.2). Furthermore, through articles 16 and 17, there is no explanation or solution regarding what measures will be enforced when appointments are continuously refused, and the inelastic quorum cannot be met. This critical vulnerability of the DSU does not address the ongoing status of disputes, nor provide further mechanisms for ensuring effective negotiation in the absence of a functioning Appellate Body, and this will be tested in practice through a legal dispute between the United States and China.



The WTO and GATT

i. World Trade Organization: Principles of Trade

The World Trade Organization (WTO) is an institution where governments can come together to negotiate trade agreements in order to settle trade disputes. "Above all, it's a negotiating forum." (World Trade Organization, para. 2) The organization holds the contracts, agreements, and rules of international trading that places each country's government within limits. These negotiations are implemented to achieve goals of helping "producers of goods and services, exporters, and importers conduct their business...meet social and environmental objectives." (World Trade Organization, para. 4).

Principles of Trade are standards that simulate an ideal trading system where every member in the WTO would experience a balance between exportation and importation of goods. Pinpointing the importance of an equal, non-discriminatory trade barrier would allow for countries to experience stability and predictability in the business environment accomplishing one of the desired goals. Alongside the encouragement for businesses to have opportunities and a sense of stability, but these principles are more accurately "a system of rules dedicated to open, fair and undistorted competition." (World Trade Organization, para. 14). The WTO principles primarily focus on the explanation of how international trade should be constructed with the idea of what goals countries should achieve in the midst.

ii. General Agreement on Tariffs and Trade

The General Agreement on Tariffs and Trade is an established foundational agreement that is breaking down international trade laws into specific responsibilities for trade to be free-flowing. These articles specify how tariffs, imported/exported goods are expected to be, and how international trade is maintained in an organized manner.

A. Allowed Mechanisms of Tariffs

Within the GATT, there are specific articles that discuss the actions of tariffs in terms of how they are supposed to be when implemented in a country. The GATT articles one and two are the main articles that discuss the mechanisms of tariffs in terms of what a country is allowed to do. The two articles focus on the importance of commitment and equality.

Article 1: General Most-Favored-Nation Treatment is an article highlighting equal treatment being reflected upon each partner country in trade. This article means that one tariff for one country should be reciprocal towards other WTO members. "...to any product originating in or destined for any other country shall be accorded immediately and unconditionally to the like product...of all other contracting parties." (Article 1.1). It is a reflection of non-discrimination and the creation of a fair competition trading ground for all. Article 1 controls how countries set tariffs and the advantages that can occur in the trading system, which emphasizes on the inexistence of discriminatory tariffs.

Article 2: Schedules of Concessions is an article reflecting on the commitments countries have agreed upon when it comes to the tariffs applied on imports. As part of the negotiation process, countries must agree upon the maximum tariff rates they can impose on imports in order to prevent countries from announcing sudden changes to the charges. Binding countries to commitments to a specific negotiated tariff on imported goods allows there to be "no less favourable" treatment occurring. This article controls the occurrence of manipulation, conversions, or protecting countries. Article 2 reflects the importance of an organized, negotiated foundational system for a smooth-flowing trading system.



B. Exceptions

As the GATT declares that there are limitations on what tariffs can do in trade, there are exceptions that countries can invoke to change their tariff rates. These trade restrictions could mean higher tariffs or redefining the rules of imported goods. However, with these exceptions, they occur in the event of an emergency or in crucial need for their country.

Article XX: General Exception is one of the articles in the GATT that is considered an exception because it allows the tariff obligation to not be applicable in necessary matters such as social, environmental, or legal scenarios. "...necessary to protect public morals...protect human, animal or plant life or health...imposed for the protection of national treasure of artistic, historic or archaeological value" (Article XX a-f). These instances that can occur in the country's situation is a reason to not be obligated with the standard tariffs agreements. This article is presenting one instance of how tariffs can be expressed differently than normal.

Article XXI: Security Exceptions is another article that is an exception to the standard tariff obligation implications. This particular article overlooks a country's ability to move past the obligations for the country's national security and the necessary need to overcome those instances. "...taken in time of war or other emergency in international relations..." (Article XXIb iii). This particular article provides countries the opportunity to deal with national security/emergencies, but the important matter in the article is that the matter can be reviewed in order to determine the article is not abused for neglect. The review process consists of panels assessing the measure to see if it is a national security, "Essential Security Interests", then the WTO will request the country to demonstrate the necessary measures specifically pinpointing the security needed against trading. This process determines the country's necessity of declaring an emergency. A reflection of how the GATT contains exceptions in order to maintain the systematic procedure.

iii. Implication of Exceptions

Article XXI can be implied in the stance of a national emergency in terms of saving domestic economic positions, specifically businesses, manufacturers, or companies. Implying this exception would allow a country to change their tariff rates in order to make the competition "fair" and advantageous. Full potential of the article can occur if the country displays full necessities for a declaration of emergency and needs to increase security. This gives the country the ability to uphold any beneficiary actions without being in violation with WTO standards. However, announcing a national emergency weakens the WTO function because when following through with Article XXI a country is no longer under the obligations of the WTO meaning the rules do not have impact on future declared trading actions. These exceptions do help countries, but they hurt the WTO/GATT procedures by pieces.

Russia - Traffic in Transit is a primary example of Article XXI, as it provides an interpretation of how the GATT article is supposed to operate. Ukraine was the complaining country, and the Russian Federation was the respondent, with the outcome that the Article XXI declaration of an emergency was within jurisdiction, making the actions taken necessary. This is an example of how the GATT Article XXI should be used. An emergency would mean the country is facing critical nationwide situations that necessitate extra precautions and protective measures, such as international conflicts or war. Even though emergencies vary in how they are interpreted and how one perceives them, in the case of Article XXI, emergencies mean a nation in a critical position, unable to function as a whole.

Case Study Analysis

China-U.S. Dispute



i. Background of the WTO Dispute

Following the United States' continuous veto of judicial appointments, in December 2019, the WTO Appellate Body was officially paralyzed, with the organ lacking the minimum quorum of three judges needed to hear cases. Two years from then, there have been 45 pending WTO disputes that are yet to be settled due to the immobilized Appellate Body, leaving many international negotiations and legal disputes undecided (Titievskaia 2021).

This case study examines a specific dispute issued by China to the United States regarding their tariffs during the period with the paralyzed Appellate Body under scrutiny, applying the outcome to test three of the paper's hypotheses (World Trade Organization 2020). Through analytical interpretation, the paper will test whether the case study proves or falsifies that the breakdown of the Appellate Body led to the increase in trade-distorting measures (H1), halted international dispute settlements (H2), or did not alter the U.S. and China's relationship at all. This specific case study exemplifies how a dispute was issued and a panel was established, but could not progress further due to the absence of the Appellate Body, allowing the paper to evaluate the given hypotheses more accurately.

ii. Analysis of WTO Proceedings in China–U.S. Tariff Dispute

Even when the Appellate Body is immobilized, the rest of the legal procedure must be followed, and this China–U.S. dispute was no exception. China initiated the dispute in 2018, requesting consultations in response to the U.S. escalating its tariffs for Chinese imports to 25% and then further requested a WTO panel to be established. In total, 14 WTO members, including the European Union (EU), Russian Federation, Singapore, and other core states, reserved their third-party rights during the original proceedings, indicating the broader attention and global economic implications this case brought.

The panel examined the United States' tariffs imposed on Chinese goods under Sections 301 of the U.S. Trade Act, which empowers the USTR to investigate and retaliate against trade-distorting measures. China challenged the tariffs, claiming that the measures were a violation of Article I:1 of the GATT 1994, the MFN principle, contending that "these duties were only applied to China's products" (World Trade Organization 2020, par. 4). They further claimed that these additional duties were "in excess of the United States' bound rates", as they were inconsistent with the schedule of concessions, the maximum duty rates that the United States and all WTO members agreed on. Ultimately, they claimed that the additional Section 301 tariffs breached several international laws and agreements concerning the GATT because the duties were imposed at rates that exceeded the tariff levels legally allowed. And in response, the United States stated that their duties were justified under Article XX(a) of the GATT, arguing that the levies were necessary for the protection of public morals.

However, the Panel concluded that they did not provide sufficient explanation demonstrating how the imposition of tariffs enhance the public morals they referenced to, ultimately ruling against the United States, recommending it to bring its violating measures into conformity. Although the initial adjudication was given, because of the Panel's lack of binding authority, the United States did not reduce its tariffs within the legally obligated rate of the WTO, and instead appealed the case to the Appellate Body. This action practically prevented the panel's findings from being implemented, leaving the dispute and the political tension between the United States and China unresolved as the Appellate Body was already paralyzed, unable to adjudicate appeals.

iii. Testing the Rise in Trade–Distorting Measures Hypothesis



This U.S.–China case study provides strong support for the Rise in Trade Distorting Hypothesis and establishes a reasonable context for potential retaliation following the unresolved dispute. If the Appellate Body was in fact active and had the minimum number of judges to adjudicate the dispute, a binding decision would have been enforced, limiting the United States' distortive policies and reducing the tariff levels on Chinese goods to return to standard rate.

However, the absence of the predominant body created a legal void and a gridlock in the international dispute resolution system. Ultimately, it failed to bring order in the global trade structure as the tariff rates of the U.S. remained at highly elevated levels. Thus, this critical case study, which exhibits the unresolved dispute between the United States and China, confirms the hypothesis by demonstrating how the lack of an authoritative adjudicatory body leads to sustained increases in trade-distorting duties.

iv. Evaluating the Deterrence of Dispute Resolution Hypothesis

This case study also serves as a clear example supporting the Deterrence of Dispute Resolution Hypothesis. The prolonged inability of the Appellate Body to process a state's appeal from the panels' adjudication effectively renders their enforcement irrelevant. While some disputes may be resolved at the consultations stage and adopt the non-binding panel's recommendation, even if a state truly questioned the adjudication, there was no official mechanism to ensure compliance. In DS543, the United States was able to maintain tariffs on Chinese goods despite the panel's ruling against them, indicating the failure of the WTO to resolve China's complaint. Overall, the case study confirms the hypothesis as it provides strong evidence that the breakdown of the Appellate Body encouraged sustained violations and deterred international trade disputes from being properly resolved through lawful enforcement.

v. Impact of the breakdown on the U.S. – China relationship

The dispute case between the U.S. and China further presents strong evidence against the Null Hypothesis, which proposed that the breakdown of the Appellate Body would not have any effect on the international relationship between the two nations. The unresolved dispute created a tangible political and economic tension between the two countries, as the United States maintained elevated tariffs on Chinese goods, continuing its aggressive trade policies against the panel's ruling. If the Appellate Body had been fully functional and able to enforce legal consequences against the U.S., compliance would likely have halted the escalation of tariffs, reducing tensions and generating a more stable trade relationship.

However, without the Appellate Body, the complaint from China was not recognized officially, indicating an institutional failure and leading to strained U.S. –China trade relations. Thus, this case study falsifies the Null Hypothesis by illustrating that the breakdown of the Appellate Body did, in fact, lead to increased political tension and affected the bilateral trade relationship between the United States and China.

The U.S. Liberation Day Reciprocal Tariff

i. Introduction and Connection with Legal Framework

The General Agreement on Tariffs and Trade includes two articles that allow exceptions from the standard tariff signed commitments. These articles are incorporated into the system to allow nations to prioritize domestic matters during emergencies. The application of the articles, when in use, allows countries to make decisions without facing restrictive consequences. Scholars argue that the original tariffs were established to build credibility and foster relationships among trading countries (Karlan and Sykes, 2025). Yet, President



Trump's desire to impose elevated tariffs began in 2018 with aluminium and steel, continuing through the 2025 Liberation Day celebration, raising arguable questions about his actions.

This case study examines the implications of President Trump's reciprocal tariffs to test three hypotheses: the WTO Article Agreement Violation Hypothesis, Permitted Tariffs Under Exception Hypothesis, and Null Hypothesis. Liberation Day is a legal challenged case study being examined as it overlooks the overwhelming increase of tariffs that are identified as reciprocal to shield the United States for protection against the growing unfairness of trade. A scholar views the Trump tariff situation as a repetition of history of former President McKinley's Tariff Act of 1890 meaning that President Trump's trading policies are similar to the 19th century when they should be building blocks of the 21st century (Mulholland 2025).

ii. Violation in the WTO Agreement

The Liberation Day case study does not align with the WTO Article Agreement Violation Hypothesis, as it focuses on the violations arising from the imposition of tariffs. Scholars find that President Trump's tariffs violate the WTO in terms of the first two articles, but the Trump administration opposes this claim. The case study does not support the hypothesis because Trump finds that his actions are necessary, but importantly, some countries have agreed to his standards. "For example, some trading partners have agreed to, or are on the verge of agreeing to meaningful trade and security commitments with the United States" (Executive Order 14257).

Executive Order 14257 is argued to be in violation with the WTO as he is establishing the actions under the validation of domestic law satisfaction. The U.S., as a founding WTO member, is obligated to follow the established policies and proceed with the required demands. However, President Trump's tariffs are not consistent with the GATT Articles I and II leading to an increased amount of complaints from other countries.

iii. Exceptions are Noted in Tariffs

The Liberation Day case study supports the Permitted Tariffs Under Exception Hypothesis to an extent because under the GATT there are two articles (XX and XXI) that permit a country to dismiss the WTO trading structure. However, the important aspect of these exceptions is that the country has to declare that it is taking these appropriate measures as its country is in an emergency. The case study supports the hypothesis to an extent because President Trump did declare that the U.S. is under an emergency due to the unjust trading system over the past years. "I declared a national emergency with respect to that threat, and to deal with that threat, I imposed additional ad valorem duties that I deemed necessary and appropriate." (Executive Order 14257).

President Trump believes that "punishing countries that have imposed unfair trade barriers on U.S. goods, will catalyze the reindustrialization of the United States." (Harithas, Meng, Brown, and Mouradian 2025, para. 8). He declares a national emergency in which Trump's imposed tariffs are exceptional due to Article XXI of the GATT. "What began as economic decline becomes a national security liability..." (Harithas, Meng, Brown, and Mouradian 2025, para. 7). Under the GATT, President Trump's tariffs are the exception meaning his actions are not in violation. This case study regarding the exception is similar to the Russia Traffic in Transit Act because the main concern was the use of the GATT Article XXI. Ukraine filed a complaint about Russia's use of article XXI as Ukraine wanted to pass through the Russian Federation to a third country. The WTO panel ruled that Russia's measure of emergency is validated because the panel recognized that the two countries were during the emergency of international relations.

When comparing the two case studies, one is recognized as an emergency while the other is not. President Trump's declaration of a national emergency due to trade, but it is not considered under WTO.



The Russia Traffic in Transit Act validates the use of Article XXI due to the international relations emergency, but Trump's declaration is aimed at combating "unfair" trade to protect domestic industries and manufacturers. President Trump's national emergency declaration is not validated due to the lack of evidence and an unjustifiable claim.

iv. No Established Relationship

The Liberation Day case study does not support the Null Hypothesis because tariffs are validated through the WTO and its members by negotiating with one another. The null hypothesis is that the WTO and the tariffs have no relationship with one another, but that is not true because Trump's tariffs must be connected to the GATT articles. Although President Trump invoked IEEPA as part of his justification for imposing tariffs, the WTO has the power to review his declaration of a national emergency. Alongside that, WTO members can file complaints about U.S. tariffs, which would mean the WTO panel would review the matter. Despite President Trump's continual reliance on domestic law for his decisions and validation, the WTO has the power to review the enforcement mechanism as a final clarification of the matter.

Recommendations

WTO Appellate Body

From the case study, it is evident that the Appellate Body could benefit greatly from amending the DSU to explicitly state the limitations that a state has compared to the DSB. In October of 2025, the United States refused the appointment of a judge for the 91st time, underscoring the ongoing disagreements between the U.S. and the organization (Knolle 2025). Through the restriction of excessive judicial overreach and modifying the DSU to include a formal written legal objection by the state rejecting the approval of a judge, the WTO would have been able to maintain the operation of the Appellate Body. While amendments aimed to completely remove individual states' involvement in the selection of judges would be unrealistic and even more destructive to the current impaired state of the international trade system, the legal ambiguity in the DSU, as has been examined in the legal analysis, necessitates an adjustment.

For every member of the WTO, they would be granted one formal objection for each appointment cycle of a judge serving on the Appellate Body. The procedure would involve the challenging state submitting a document with legally grounded reasons for their objection to the DSB. They will then engage in multiple consultations with the DSB regarding the appointment of the judge under a designated time frame, to ensure mutual agreement. This adjustment to the DSU would first enable the DSB to restore the Appellate Body from its paralysis to function as the United States will have difficulties justifying their repeated rejection of judges on 91 separate occasions. While the amendment will be enforced by the DSB, any modifications to the DSU requires a consensus among all WTO members, thus requiring the agreement of the United States.

However, considering the current relationship between the WTO and the U.S., the immediate approval to limit the United States' power seems unlikely without any additional benefits. Therefore, the paper's second recommendation is to follow the United States' proposed suggestions to rebuild trust. The United States has long complained about certain structural weaknesses in the WTO and criticized its unwillingness to accept those evident errors. To address one of the concerns regarding the WTO secretariat's increasing involvement in the adjudication of international disputes alongside the Appellate Body, Hirsh proposed to abolish the group and replace them with legal clerks (Hirsh 2020).

Similarly, to adhere to another genuine concern that is not exclusive to the United States but is shared at the global level, the WTO should reconstruct the developing country benefits. The United States argues that the current mechanism of self-claiming developing country status reflects a broader weakness in



WTO's legal enforcement and in practice, it does not offer a realistic representation of the society. Among the two-thirds of the WTO members that receive the developing country benefits, the WTO should force certain economically advanced countries to stop claiming those benefits (World Trade Organization n.d.). This adjustment would be a crucial step in rebuilding a credible relationship with the United States as the overall tension began from simple institutional disagreements like such. This will further ensure certainty in reactivation of the Appellate Body as without the United States' agreement, the amendment in the DSU can never be achieved, thus having no effect on the current stagnated state of international trade dispute system.

Overall, the Appellate Body's paralysis reflects legal ambiguity within the DSU and other institutional disagreements between the WTO and the United States. Imposing limits on repeated objections to judicial appointments could restore functionality without undermining individual state's sovereignty, but such reform relies heavily on the consent of the United States. Addressing U.S. concerns over Secretariat involvement and developing country status is therefore essential to rebuilding trust and reactivating the Appellate Body.

WTO and GATT

The hypotheses and the case study of Liberation Day propose the relationship between the imposed tariffs and the WTO in the matter of violation with one another. The question that is still to be answered is whether President Trump is in clear violation of the WTO, or if the declaration exempts him from violations with the WTO. Debating and trying to break down the President's argument of purpose may be beneficial, but modifying the articles for clarity, precision, and understanding would maintain the international trading system framework.

When examining the evidence, scholars have found that the "reciprocal" tariffs are unilateral proving the violations, but the case study presents the usage of exceptions as justification. While the current WTO provides structure and a precise viewpoint on trade, the key aspect is the interpretation of the articles. Modifying particular articles in the GATT would provide clarity in what is restricted or allowed. For instance, Article XXI of the GATT is about National Security meaning countries can declare an emergency for the protection and giving the authority to break WTO commitments for the sake of the nation.

However, there is controversy because countries can self-judge and declare these emergencies leading to possible abuse despite there being review procedures as confirmation it is not enough. Proceeding with the modification of the GATT article would follow a lengthy procedure to ensure that the WTO members and the Ministerial Conference agrees upon the matter. For the process to begin, a member must propose an amendment to the Ministerial Conference, which will be decided upon by majority vote. Then WTO members must present their acceptance to the amendment in order to move forward with the modification process to take effect. By completing this process an article's framework is being reframed presenting the new modification.

Secondly, the research not only focuses on the violations and impacts of President Trump's tariffs, but the mention of the imbalance it creates in the WTO and trading competition. The WTO stands by the concept of balance and equality to maintain relationships for countries in order to provide development and inclusivity. Modifications would allow the balance to be secure, but it would help address specific needs for countries in the matter of exporting/importing goods. The modification process would allow countries to receive benefits alongside the ability for better cooperation between one another. Proposing modern modifications to the GATT such as articles XX and XXI within the WTO would allow for a more understandable and clear framework structure that countries would be able to recognize without misinterpretation preventing countries from abusing such power.

The Liberation Day case study highlighted a gap in the WTO stemming from misinterpretation and abuse of articles for personal gain. Although certain actions are under review and declaration if the measures were necessary, a change in the WTO is an essential action that must be taken as time passes by with new



developments. “The next evolution the multilateral rules-based trading system needs may not be another workaround, but a reset of the rules governing how governments can intervene to shape trade.” (Tipping 2025, para. 14). Resetting or modifying the WTO would allow the organization to improve and grow with the progress of time to ensure that countries are receiving essential. Tipping agrees with the concept of modification as she argues that the WTO must change to keep up with governmental pressures and provide opportunities.

In the end, proposing these modifications to the WTO would allow for the organization to grow and follow the process of time in the matter of restrictions. The implementation would present a unified agreement with the members and the council presenting the acceptance of change leading to legal effectiveness for ratification into the international trade law system. The modification process would allow for the overlooking and abuse of certain principles to be stricter or more flexible depending on the responses when in use. Making these changes can help countries and the international trading system be more unified alongside balanced in the future.

Conclusion

This paper has argued that the United States’ efforts that potentially undermine the WTO dispute settlement, particularly through the sustained veto for the appointment of the Appellate Body judges, has enabled a shift toward unilateral tariff measures that are justified through GATT Articles XX and XXI but often lack the fundamental evidences required by those exceptions, raising legal questions for the policies and many international disputes unresolved. Through legal analysis and a case study of the U.S.–China tariff disputes and Liberation Day, the paper demonstrated that these measures were legally vulnerable yet remained with impunity due to the Appellate Body’s paralysis. It further showcased the impact of the Appellate Body’s inability to adjudicate disputes had on the relationship between the U.S. and China, confirming the hypothesis that the breakdown of the Appellate Body has resulted in the rise of tariffs and weakened the multilateral trade system. Without approvals and reviews of actions, the legality of tariffs would be questioned, but importantly, the validation and justification of the action is to be determined. The increasing tariffs titled as reciprocal present how, without the WTO, the principles can be misinterpreted and bent in certain ways to benefit the country in action.

Although some may argue that the trade relations between the United States and China were already deteriorating before the Appellate Body’s breakdown, the evidence presented suggests that the absence of the Appellate Body was a driving force in accelerating the diplomatic conflicts. Without a functioning Appellate Body, violation of the WTO’s underlying principles has become increasingly normalized, contributing to a less credible international dispute settlement mechanism. The international trading system became weaker in the sense of forgotten obligations and a lack of enforcement mechanisms to help the trading process. The arguments of how these issues have been long-standing since the very beginning of time, so it is not dependent on the current time, but it has progressively gotten worse. The Appellate Body and the unilateral tariffs are occurring due to the WTO’s inability to fully function with the growing fragmentation of international law. Further research on this topic should explore the impact of the more recent trade war between the U.S. and China on the WTO and whether any other amendments can be made to reverse the implications, alongside exploring the reciprocal tariffs’ effect on how it is shaping the international trading system and relationship with trading countries. This research is necessary to determine the future trajectory of the international trading system. It can also help make an estimation of how the system may need to be adjusted in the future, in consideration of deepening disagreements and a collapsing dispute settlement system.



Bibliography

1. Bacchus, James. "Do World Trade Organization Laws Still Exist?". CATO Institute. 2024. Accessed December 22, 2025. <https://www.cato.org/commentary/do-world-trade-organization-laws-still-exist>
2. Budner, Ben. "The Questionable Legality of IEEPA Tariffs: Does the Major Questions Doctrine Apply?". Texas Law Review. 2025. Accessed December 30, 2025. <https://texaslawreview.org/the-questionable-legality-of-ieepa-tariffs-does-the-major-questions-doctrine-apply/#:~:text=Next%2C%20Part%20III%20examines%20recent,limits%20on%20presidential%20trade%20powers>
3. Harithas, Barath, Meng, Kyle, Brown, Evan, and Mouradian, Catharine. "'Liberation Day' Tariffs Explained". CSIS. 2025. Accessed December 28, 2025. <https://www.csis.org/analysis/liberation-day-tariffs-explained>
4. Hillman, Jennifer. "A Reset of the World Trade Organization's Appellate Body." Council on Foreign Relations, 2020. <https://www.cfr.org/report/reset-world-trade-organizations-appellate-body>
5. Hirsh, Bruce. "Resolving the WTO Appellate Body Crisis: Proposals on Overreach." paper commissioned by the National Foreign Trade Council (December) (2019). https://www.nftc.org/archive/Trade%20Policy/WTO_Issues/Resolving%20the%20WTO%20AB%20Crisis%20vol2%2006042020.pdf
6. Hopewell, Kristen. "Unravelling of the trade legal order: enforcement, defection and the crisis of the WTO dispute settlement system." International Affairs, Volume 101, no. 3, (2025), 1103–1117. <https://doi.org/10.1093/ia/iiaf055>
7. Horn, Henrik and Petros C. Mavroidis. "Why the US and the WTO Should Part Ways." VoxEU, Centre for Economic Policy Research (CEPR), 2025. <https://cepr.org/voxeu/columns/why-us-and-wto-should-part-ways>
8. Karlan, Pam & Sykes, Alan. *Trade Wars, Economic Chaos, and Law: Unpacking Trump's Trade Tactics with Alan Sykes*. Stanford Legal (SLS Podcast). 2025. Accessed December 22, 2025 <https://law.stanford.edu/stanford-legal/trade-wars-economic-chaos-and-law-unpacking-trumps-trade-tactics-with-alan-sykes/>
9. Keskin, Goktug. *Trade Wars and the WTO: Navigating Trump's 2025 Tariffs*. Atlas Institute for International Affairs. 2025. Accessed December 22, 2025. <https://atlasinstitute.org/trade-wars-and-the-wto-navigating-trumps-2025-tariffs/>
10. Knolle, Kirsti, "US blocks WTO proposal to fill Appellate Body vacancies for 91st time, says trade official." Reuters, October, 2025. <https://www.reuters.com/business/us-blocks-wto-proposal-fill-appellate-body-vacancies-91st-time-says-trade-2025-10-24/>
11. Lamp, Nicolas. *What President Trump's "Reciprocal" Tariffs Mean for International (Trade) Law*. EJIL:Talk!. 2025. Accessed December 22, 2025 <https://www.ejiltalk.org/what-president-trumps-reciprocal-tariffs-mean-for-international-trade-law/>



12. Mulholland, Ryan. “Why Is Trump Pursuing a 19th Century Trade and Economic Agenda in the 21st Century?”. CAP. 2025. Accessed December 28, 2025
<https://www.americanprogress.org/article/why-is-trump-pursuing-a-19th-century-trade-and-economic-agenda-in-the-21st-century/#:~:text=Exporters%20are%20also%20not%20directly,%2C%20labor%20rights%2C%20and%20corruption>
13. Sesti, Madeline. “Background on the WTO and recent international trade”. Michigan Journal of Economics. 2025. Accessed December 22, 2025
<https://sites.lsa.umich.edu/mje/2025/04/03/background-on-the-wto-and-recent-international-trade/>
14. Sherman, Natalieiii and Jillian Josephs. “China challenges Trump tariffs as ‘discriminatory’.” BBC News, 2025. <https://www.bbc.com/news/articles/c805m1r4m5no>
15. Stewart, T. P. “WTO Arbitration Report On China’s Challenge To U.S. Countervailing Duty Investigations — While Retaliation Is Much Smaller Than China Sought, Core Problems With Original Appellate Body Decision Flags Challenge To Restoring The Dispute Settlement Binding Process.” Washington International Trade Association (WITA), 2022.
<https://www.wita.org/blogs/wto-arbitration-report-china/>
16. The White House. “Further Modifying The Reciprocal Tariff Rates”. 2025. Accessed December 28, 2025. <https://www.whitehouse.gov/presidential-actions/2025/07/further-modifying-the-reciprocal-tariff-rates/>
17. Tipping, Alice. “What We Should Be Talking About When We Talk About World Trade Organization Reform”. IISD. 2025. Accessed December 30, 2025
https://www.iisd.org/articles/explainer/what-we-should-be-talking-about-world-trade-organization-reform#:~:text=The%20WTO%20reform%20agenda%20includes:%20*%20Resetting,investment%20rules%20*%20Import%20and%20export%20restrictions
18. Titievskaja, Jana. “International trade dispute settlement: WTO Appellate Body crisis and the multiparty interim appeal arrangement”. European Union, 2021.
https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/690521/EPRS_BRI%282021%29690521_EN.pdf
19. World Trade Organization. Dispute settlement activity - some figures. WTO Dispute Settlement Statistics, 2024. https://www.wto.org/english/tratop_e/dispu_e/disputstats_e.htm
20. World Trade Organization, DS543: United States — Tariff Measures on Certain Goods from China.” 2020. https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds543_e.htm
21. World Trade Organization. “General Agreement on Tariffs and Trade (GATT 1947)”. Accessed December 22, 2025.https://www.wto.org/english/docs_e/legal_e/gatt47_e.htm
22. World Trade Organization. *Principle of the Trading System*. Accessed December 22, 2025.
https://www.wto.org/english/thewto_e/whatis_e/tif_e/fact2_e.htm
23. World Trade Organization. Understanding on rules and procedures governing the settlement of disputes (DSU). Annex 2 of the Marrakesh Agreement Establishing the World Trade Organization. Accessed December 21, 2025.
https://www.wto.org/english/tratop_e/dispu_e/dsu_e.htm



24. World Trade Organization. n.d. "Understanding the WTO: Developing Countries." Accessed December 30, 2025. https://www.wto.org/english/thewto_e/whatis_e/tif_e/dev1_e.htm
25. World Trade Organization. "WTO Dispute Settlement: One- Page Case Summaries Russia - Traffic in Transit". Accessed January 4, 2026. https://www.wto.org/english/tratop_e/dispu_e/cases_e/1pagesum_e/ds512sum_e.pdf



EVALUATING INTERNATIONAL HEALTH AND EDUCATION LAW: INEQUALITY DURING COVID-19

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Abstract

The COVID-19 crisis revealed larger gaps between inequalities for the access of essential resources, especially vaccines and education, between developing and developed countries. This research paper hopes to examine whether the current international legal law under organizations such as the WHO (World Health Organization) and UNESCO were enabled to provide fair access to resources during a worldwide pandemic. Using a research and literature-based analysis of international laws, weak frameworks, and scholarly interpretations published before, during, and after the pandemic, the study discusses the effectiveness of legal laws controlling global health and education. While international law does focus the access to healthcare and learning essential, these frameworks mostly depend too much on continuous realization, collaboration, and unenforceable recommendation. Case studies focusing on COVAX vaccines spreading and education systems in Sub-Saharan Africa displays the lack of right for authority to allow richer countries to focus more on national interest within vaccine distribution and stronger digital education architecture frameworks without crossing international law's interests. The paper concludes with the result that pandemic-era disparities were pressured not only by organizations' failure, but also due to the structural constraints of international legal law. It states that without legal techniques, emergency funding, and required burden-sharing, international organizations still stay incapable of correcting global inequalities during emergency crises, undermining the need for legal change in global health and educational systems.

Keywords

International Law; COVID-19; Vaccine Inequality; Education Inequality; WHO; UNESCO

Introduction

The progress of life expectancy has always depended on our ability to discover cures and treatments that could save not only individuals, but entire populations. Behind every medical crisis or disease, there are international efforts to guarantee vaccines globally that can change the trajectory of a health crisis. Throughout history, some of the deadliest epidemics have devastated populations, such as Antonine Plague (165 – 180 AD), the Black Death (1346 – 1353), the seven cholera pandemics (1817 – present), HIV/AIDS (1981 – present), and Severe Acute Respiratory Syndrome (SARS) (2002 – 2003) (Sampath et al. 2021). In each case, the effort to introduce cures to larger populations shows the importance of global health, laying the foundation for modern vaccine distribution. Similarly, the COVID-19 pandemic showed how international legal frameworks influenced the distribution of vaccines. Moreover, as schools closed and education systems shifted to remote learning, education became unevenly distributed, leaving disparities as global issues remained unresolved. However, the disparities between developed and developing states were not entirely addressed during the pandemic. Despite these challenges, the global distribution of education and vaccines is essential in times of health crisis.



Methods

A search for relevant literature was conducted using Google Scholar, with a focus on papers published in the last five years, by searching the keywords vaccine access, WHO, UNESCO, education, equality, and COVID-19. This method yielded relevant papers, mostly perspectives and evaluations of existing legal frameworks by scholars, and the papers were categorized based on chronological order. There were three groups for analysis: before the pandemic, during the pandemic, and after the pandemic. These were research publications freely accessible to the public. In addition, international institutions' websites were also utilized to locate primary sources.

Literature Review

The COVID-19 pandemic showed inequalities in access to essential public goods such as education and pharmaceutical resources between developed and developing countries. According to the UN Trade and Development (UNCTAD) website, countries could be classified into developed and developing countries based on their economies (UNCTAD 2025). This economic classification helps explain why access to education systems and vaccines differed significantly during the pandemic. Since the classification is based on each country's income levels, infrastructure qualities, healthcare capabilities, and organizational empowerments, it becomes a stress test for all international governance systems, divulging long-term structural disparities in both educational and healthcare access. According to the literature review, several inequalities were not recently made by COVID-19 but instead, intensified by the pandemic (Education Monitoring Report 2020) (Lennox et al. 2021).

I. Access to Vaccines

Before COVID-19, international law already recognized the importance of sharing knowledge and health-related resources. Article 15 of the Universal Declaration on Bioethics and Human Rights (2005) established that scientific knowledge should be shared globally, especially with developing countries, supporting access to healthcare and technology like vaccines before the pandemic. Nevertheless, it was not a treaty and did not create legal obligations for the members of UNESCO (UNESCO 2006).

Furthermore, based on existing laws, in Human Rights and Access to COVID-19 Vaccines, the United Nations Human Rights Organization demanded that countries treat vaccines as a global public good immediately following the outbreak of the COVID-19 pandemic. To achieve this, it suggested nations must engage in international cooperation by sharing scientific knowledge and avoid accumulating resources by certain countries. Also, states should be required to use transport protocols to include everyone in vaccine distribution plans and provide accessible health information in various languages to fill the digital gap between countries (United Nations Human Rights Organization 2020).

Supporting the declaration, scholars claimed that wealthy nations used Advance Purchase Agreement to secure vaccines in advance and implement export controls that prevent vaccine distributions to other countries during COVID-19 in 2020, increasing the health gap between developed and developing countries. Poorer nations generally lacked the financial resources to compete in the high-demand vaccine market and the legal power to challenge wealthy nations. To solve this, the scholars recommended shifting toward multilateral agreements like the COVAX and creating international frameworks that treat vaccines as public goods rather than products for the highest bidder (Phelan et al. 2020).

However, scholars investigated whether this legal framework worked in practice during and after the pandemic and discovered flaws, proposing new solutions. Scholarly evaluations of COVID-19 outcomes include Emory International Law Review during the pandemic, where it claims that wealthy nations use their wealth to accumulate the vaccine supply through private contracts, while some developing nations claimed "ownership" over virus samples to demand a fairer share of the resulting medicine. The article also suggested that a permanent pandemic treaty could fix these issues by creating binding rules that require



all nations to share information and health goods more fairly during a crisis (Halabi and Santos Rutschman 2021).

Benavides claimed that international laws prioritized protecting profits and patents, allowing wealthy countries to buy and hoard vaccine supplies (Benavides et al. 2023). Similarly, Akcali Gur argued that international law failed to guarantee fair access because it lacks binding rules for sharing technology and allows powerful states to prioritize their own economic goals (Berna Akcali Gur and Kulesza 2024). Likewise, Agampodi also claimed that intellectual property laws protect private patents and enabled vaccine nationalism through bilateral legal agreements (Suneth Agampodi et al. 2024). Thus, many scholars agree that international law failed during COVID-19 because it lacked enforceable, binding mechanisms to override national self-interests.

In response to these widely identified legal failures, international organizations attempted to reform the global legal framework by developing COVID-19 specific mechanisms targeted at correcting inequities in vaccine access across countries. During the COVID-19 pandemic the World Health Organization launched COVAX as a historic multilateral effort to ensure vaccine equity though it depended on donations and surplus sharing and concluded on 31 December 2023 (WHO 2020). After the pandemic, in May 2025, the WHO Pandemic Agreement introduced Article 11 to promote technology sharing and lower patent barriers for manufacturers in developing countries ("WHO Pandemic Agreement" 2025). Building on this approach the World Health Assembly adopted a pandemic agreement that established the Pathogen Access and Benefit Sharing system requiring manufacturers to give the WHO 20 percent of vaccines and treatments during emergencies and creating a Global Supply Chain and Logistics Network while still ensuring national sovereignty (WHO 2025). However, these new legal frameworks remain largely non-binding, making it necessary to examine other cases to evaluate whether they are truly effective in correcting global inequities.

II. Access to Education

Existing research on pandemic-era education emphasizes how school closures worldwide disproportionately impacted developing nations. According to the UNESCO management reports and diverse education case studies, low access of support towards internet connectivity levels, different access to devices, and inefficient teacher education led remote learning to become inequitable for large portions of the low-income countries. (Education Monitoring Report 2020) On the other hand, studies directed on the wealthy nations such as the United States, describe that pre-existing infrastructures were stronger and digital learning applications were already in place for a faster shift towards online education, even being inclusive towards all inequalities existing within those communities (Education in a Post-COVID World 2020).

Experts analyzing the international human rights law highlight that the right to education is still being firmly acknowledged throughout instruments such as the ICESCR and UNESCO frameworks. UNESCO's Right to Education Handbook and General Comment Number 13, the right to be educated is generalized through the 4 values: availability, accessibility, acceptability, and adaptability (UNESCO 1999). But, several scholars ground their research that standards aren't met during the crisis because of the weak enforcement techniques, especially in the global standard.

Throughout works of health related scholars, especially the WHO, comments describing vaccine inequalities could be identified. According to public health and international law scholars, techniques such as COVAX were unsuccessful in providing equal access to education due to their reliance too much on necessary voluntary help and overlooking the high payments made by wealthy countries (WHO 2021). These results provide ideas that international organizations were lacking the proper power when it came to compelling with fair expansion, responding to the real weaknesses identified in governing systems.

Different authors compared unsuccessful results of vaccine expansion with failures of education structures. According to several governance analyses, both results were mainly structured around weak laws, policy instructions, and non-regulated frameworks (Burnett 2015). Most scholars define that while these



approaches may create useful standards, it was proven inefficient during an urgent global era that needed harsh obligations and reexpansion of materials, especially vaccines.

The UNESCO Education 2030 Framework, utilized before COVID-19, is incredibly ambitious but systematically limited (UNESCO 2024). The framework mainly commits countries to SDG 4 targets, including making sure that quality education is inclusive towards everyone, expanding ICT access, and decreasing inequality rates throughout education outcomes by 2030.

However, evaluations published during and post pandemic provide an idea that UNESCO lacked techniques to strengthen these goals when school closings happened. More specifically, the framework did not provide legal requirements or emergency financing to talk about unequal digital infrastructure, making low-income countries suffer with limited resources such as lack of teacher training to meet SDG 4.1 and 4.a targets (Sustainability 2020).

Critical articles going over post-pandemic standards identify that international institutions such as UNESCO have increased attention towards remote learning, its resilience, and preparation for the crisis. On the other hand, according to critical policy analytics, the newer policies still rely highly on voluntary compliance and extra funding, which raises continuous criticism about the court's capability to highlight structural disparity in future crises.

III. Conclusion

Overall, the COVID-19 pandemic demonstrated how UNESCO and WHO failed to provide binding force and implement enforcement mechanisms, preventing developing countries from having equitable access to education and vaccines. Despite ethical considerations and post-pandemic reforms, international laws continued to lack enforcement and let developed countries to perform voluntary cooperation, leaving inequalities unresolved.

Statements of Hypothesis

H1: Existing international legal frameworks failed to ensure equitable access to vaccines and education during the COVID-19 pandemic.

This hypothesis states that international laws may have failed to secure equitable access to COVID-19 vaccines and education between developing and developed states because existing legal frameworks lacked binding authority and effective enforcement. While international organizations promoted equal access to private resources like vaccines and remote education tools, commitments from developed countries remained voluntary. This may have allowed states to prioritize national self-interests through bilateral agreements and patent protections that could have influenced vaccine supply during the pandemic. As a result, a vaccine market shaped by economic self-interest and private patents could have contributed to disparities between developed and developing states. Likewise, in education, the absence of binding obligations under international frameworks may have contributed to unequal access to remote learning, showing disparities in access to educational resources and digital goods during the pandemic.

H2: International legal frameworks under the WHO and UNESCO lack the legal power to compel states to provide vaccines and ensure equitable access to education.

The WHO and UNESCO are represented as coordinating bodies across nations but may have lacked sufficient legal authorities to provide vaccines to developing states or ensure them equitable access to education. Their legal frameworks mostly rely on state consent and voluntarism rather than enforcement mechanisms unlike the Security Council, which may have limited compliance during the COVID-19 pandemic. Without binding powers or severe sanctions on developed countries, these wealthier states could choose whether to share resources or pursue economic benefits. In education, UNESCO also merely "recommended" international laws constructed for equality, which may have allowed states to respond differently to remote learning technology transfers based on interests in their own economy, showing



unequal access to online education and digital resources. This structural limitation may have reduced the effectiveness of global cooperation and efforts, allowing unequal vaccine and education distribution patterns to persist. Consequently, flaws in legal authority under the WHO and UNESCO could have contributed to disparities in vaccine access and educational opportunity between developed and developing states.

H3: International organizations such as WHO and UNESCO lack the financial resources to provide vaccines and equal access to education to the developing world due to pre-existing inequalities.

International law was proven insufficient due to disparities already existing, creating gaps between developed and developing countries, which maximizes the pragmatic influence of global policy frameworks. This hypothesis states that inequalities within status, digital architecture, healthcare capabilities, and educational limitations eventually equaled well-intentioned global obligations that could not be in place fairly. Under this reasoning, international law was not successful not only due to the poor outer layer alone, but also due to it being operated within a global mechanism already characterized by unequal distribution of resources, making continuously equal access towards education devices and vaccines hard to attain during an emergency crises. Hence, even international norms created for a beneficial purpose were applied unequally among states, reflecting continuous structural constraints compared to the equal legal failure. This statement suggests that pandemic-era disparity was portrayed by pre-existing global disparities that international law was incapable of attaining the maximum capacity to overcome in the short term.

H4: UNESCO and the WHO did not fail to provide resources, such as vaccines and access to education, during the COVID-19 pandemic.

UNESCO and the WHO did not give access to important public essentials, such as education and vaccines, during the pandemic. This hypothesis asserts that institutions operate only within the limits of their legal instructions, which do not force legal incentives to straight forwardly provide resources to countries. Under international law, organizations such as UNESCO and the WHO mainly work through direct guidance, cooperation, and voluntary help compared to obligatory power or redistribution. From the perspective of organizations, the non-existence of universal access does not account for organizational failure, as these institutions were not really required to absolutely provide equal outcomes. To add on, both organizations did provide support through different policy instructions, technical help, emergency funding techniques, and initiatives such as COVAX. Therefore, inequalities in access may be assigned to country-level capability and implementation compared to any-or-all shortcomings of international organizations themselves. This assertion treats unequal results as an outcome of structural restriction rather than organizations ignoring or legal failure.

Legal Question

What do international lawful guidelines controlling education and global healthcare make mandatory for states during a crisis, and to what extent did the relocation of authority and strengthening techniques within the educational frameworks restrict institutions such as UNESCO and the WHO's capabilities to minimize impacts of pandemic-era inequality? Specifically, did countries infringe any international laws, including education and health, or did the law restrict its own power?

I. Education: UNESCO, ICESCR, and the Right to Education

The most utilized and useful source when it comes to defining the right to education is the International Covenant on Economic, Social and Cultural Rights (ICESCR), specifically Article 13, which incentivizes countries to voluntarily provide free and accessible quality education and to continuously make sure secondary and eventual college education is also accessible. Article 2 of 1 of the ICESCR mostly requires states to focus more on the process of "maximizing the resources available" towards the acknowledgement of rights, while Article 2 of 2 highlights the non-discrimination.



Moreover, the supplementary reliable translation is provided by the Committee on Economic, Social and Cultural Rights' General Comment No. 13, which further deepens the reasoning on the right to education through the "4a" guidework: accessibility, acceptability, adaptability, and availability. These 4 standards once again discuss how education must be accessible both economically and physically, also inclusive, and adaptable to social shifts.

At the organizational level, UNESCO is characterized by the UNESCO Constitution (Article 1). UNESCO advocates for education through cooperation, standard-creation, and advice, but still does not provide any strength or power. Key policy guidelines involve the Incheon Declaration and Education 2030 Framework for Action, which specifies SDG 4, including several subgoals of SDG 4.1, the goal to provide free, equal primary and secondary education, and SDG 4.a, the goal to make legal, inclusive, and efficient learning environments, including the ICT architecture.

In Article 13 of ICESCR, countries are clearly incentivized to make sure access to education is provided for everyone, even during emergencies. While the Covenant lets there be room for time-consuming acknowledgement, this does not allow for there to be any discrimination within countries' status. On the other hand, the treaties do not specifically state any necessary needs for digital education, emergency cooperation, or teacher training in progress. This invisible silence creates a huge real gap during the pandemic, especially when education is shifted to be 100 percent online.

Through systematic operation, UNESCO's policy guidelines must be read in parallel with the ICESCR. UNESCO lacks the right under its Constitution to mandate that states reassign national wages, invest in broadband internet infrastructure, or require sudden teacher training, as no article of the UNESCO Constitution provides enforcement mechanisms or permits sanctions for non-compliance. For example, Article I limits UNESCO's role to recommendations and coordination, explicitly respecting state jurisdiction over education operations.

The Incheon Declaration clarifies this limitation distinctly. Paragraph 14 of the declaration states to "mobilize resources" and "strengthen international cooperation," but it does not create legal obligations, chronological orders, or punishments for unsuccessfulness for failing to meet SDG 4 targets. Alternatively, compliance depends on voluntary reporting, peer review, and political achievement compared to legal accountability. This design unsupported the framework's efficiency during the emergency, when quick, compulsory action was mandated.

A teleological interpretation recommends that education has to stay available to everyone during a crisis. However, during COVID, several low-income states were unable to meet the goals of SDG 4 due to a lack of internet. According to UNESCO monitoring reports and comparative education case studies, this resulted in eventual huge violations of accessibility and adaptability, especially for rural students, girls, and the most vulnerable groups.

The ICESCR primarily relies on the reports of states and each state's review, but UNESCO does not have the legal right to propose consequences or require emergency funding. Therefore, even when laws are violated, international law cannot provide any effective pathway to eventual success because of the voluntary nature of the agreements.

International education law creates strong standard-based promises but is backed up by weak enforcement structures. During COVID-19, states could comply in business with UNESCO involvement while continuously failing to provide equal access to education, portraying the legal framework channels' behaviors as a persuasion act compared to compulsion.

II. Vaccine: WHO, IHR, and ICESCR

The WHO Constitution establishes the foundational principles for global health cooperation. It recognizes unequal development in health promotion and recommends that the states themselves ensure equality. This provision identifies inequality as a shared risk but does not impose a duty on states to redistribute



health resources. No article assigns enforcement authority to the WHO or creates penalties for not complying.

The International Health Regulations provide coordination mechanisms but depend on non-binding language. The IHR defines Standing Recommendations as “non-binding advice issued by WHO for specific ongoing public health risks” and Temporary Recommendations as “non-binding advice issued by WHO on a time-limited risk-specific basis.” The repeated use of the term non-binding confirms that states are not legally required to comply with WHO guidance, including guidance related to vaccine distribution.

The IHR further limits enforcement by defining health measures as actions that “do not include law enforcement or security measures.” This explicit statement removes any coercive capacity from the regulatory framework. The authority granted to the WHO is therefore weak rather than compulsory.

Article 3 of the IHR further weakens binding obligations by affirming that states have the “sovereign right to legislate and to implement legislation in pursuance of their health policies.” This functions as an exception allowing states to prioritize domestic interests while remaining formally compliant. Member state statements reinforce this interpretation. The United States declared that the IHR “do not create judicially enforceable private rights. Brazil similarly declared that recent amendments carry a “recommendatory status.”

The ICESCR recognizes international cooperation but structures it through recommendation rather than compulsion. Article 23 states that international action includes “the adoption of recommendations” alongside technical assistance and consultation. This language places recommendations at the center of enforcement and does not require material transfers.

Article 21 provides that ECOSOC may submit reports containing “recommendations of a general nature.” Article 19 allows state reports to be transmitted for “study and general recommendation.” Article 20 permits states to comment on recommendations rather than comply with them. These provisions collectively establish a supervisory system based on dialogue rather than obligation.

Therefore, no article authorizes sanctions, provides resolutions to disputes, or enforces compliance. This may have led developed states to fulfill reporting duties without altering behavior.

Thesis Statement

The international law was unable to ensure equitable access to essential public goods—such as education and vaccines—between developed and developing states during the COVID-19 pandemic due to weak institutional authority and a lack of binding rules. Although the International Covenant on Economic, Social and Cultural Rights (ICESCR) states that access to both education and healthcare is mandatory, its dependence on continuous realization and reporting-based obedience limited its efficiency during the pandemic, allowing developed countries to dominate the vaccine and digital education materials without violating international law. International instruments such as the WHO Constitution and the IHR formally recognized inequality as global concern, but their recommendatory language and support for state sovereignty limited their effectiveness. Non-binding rules identified by the UNESCO and WHO such as the Education 2030 Framework for Action and COVAX further demonstrated how international institutions depended on voluntary compliance rather than legal obligation. Many scholars also contended that intellectual property protections and national self-interest were legally allowed under established frameworks. Consequently, states could formally comply with current international law without sharing public goods, leaving international institutions unable to hold states accountable as the rules functioned as recommendations.

Case Studies

I. Education in Sub-Saharan Africa



Using Kenya as a primary example, this case study demonstrates why UNESCO's education guidelines were unsuccessful in preventing the deepening of educational inequalities during the COVID-19 pandemic. This study looks over both the long-term traditional vulnerabilities in education mechanisms and the short-term interruptions caused by the pandemic. Instead of aiming for a statistical generalization, this case study provides a deeper context to argue claims in the documents considering the limits of international education administration, specifically UNESCO's dependence on optional instruction, voluntary obedience, and country-led implementation compared to obligatory lawful rights (UNESCO 2021; Burnett 2015). The analysis is based on regional learning-loss data from Science Direct, and Kenyan education materials to grade how worldwide education goals were interpreted into reasonable boundaries during emergency situations (Lazaro, Lorente, and Pulido-Montes 2020).

Pre-existing literature continuously states how education systems in Sub-Saharan Africa faced COVID-19 with obvious structural limits. World Bank and UNESCO documents state that the era before pandemic education operations in the Sub-Saharan region were labelled as persistent, high-level teacher training, limited digital architecture, and unequal access between both cities and suburban populations, which especially restricted emergency responses (World Bank 2020; UNESCO 2020a). Disparities between poor and wealthy countries, especially in the quality of resources, affect the quality of educational results during emergencies (UNESCO 2020b).

According to the Kenyan Ministry of Education and National Education, the expansion of free, quality education since 2003 increased enrollment in high-level colleges, but failed to acknowledge the country's slow pace in providing efficient provisions, mentors, and resources (Government of Kenya 2019). Therefore, inefficient teacher recruitment, and limited technological capability continued long before the pandemic itself. These unintentional incapacities reduced the system's ability to modify when schools closed.

These unfortunate lacking issues prove that access to education in Kenya was already unequal before the pandemic. While international frameworks such as UNESCO's Education 2030 Framework for Action, the Incheon Declaration, and Sustainable Development Goal 4 outlined plans for equal access, domestic execution relies on the country's capacity and political willingness (UNESCO 2015). Therefore, the education operating system was already weak and vulnerable to external shocks, particularly one as powerful as a global pandemic.

Literature widely calls COVID-19 a "stress test" for global governance operations, meaning that the emergency revealed vulnerabilities in pre-existing organizational arrays by placing extraordinary pressure on them compared to simply creating new problems (Burnett 2015; UNESCO 2020a). In Sub-Saharan Africa, continued school closures negatively affected students who lacked access to electricity, digital infrastructures, or the internet itself. Learning activities already declined at a sharp rate during the crisis, with low-income homes incredibly less likely to attract children in any type of online learning.

Evidence from Malawi demonstrates the more vague regional base. Long-term data state that students went through learning losses almost to nearly two or less years of school, with more than half of the loss being after schools reopened due to a decreased speed of learning (ScienceDirect 2021). This part shows that education mechanisms not only failed to give efficient online education in times of schools closing, but also didn't have enough capacity to regain losses afterward. These results strengthen the argument that international education goals did not equal crisis-strong national systems.

Kenya, specifically, provides a special exemplifying micro-case of how pandemic-era inequality unfolded. Public facilities, like schools, already overloaded before the pandemic, were incapable of shifting perfectly to remote education. Lack of numbers of teachers, overpopulated classrooms, and underdeveloped digital infrastructure all contributed to the inaccessible education for most children (UNESCO 2020a). On the other hand, private schools, which serve more rich families, were able to quickly change to digital applications, continuing the education students deserve.



According to socioeconomic data provided in Science Direct, two-thirds of the population lives on less than two dollars per day, making entrance to private school almost impossible economically (ScienceDirect 2021). This harsh reality worsened educational qualities during the pandemic, because only a slight segment of children could receive uninterrupted learning. Therefore, the pandemic increased educational gaps between socioeconomic lines compared to simply showing them, enforcing pre-existing disparities.

At the end of the day, this case study shows that UNESCO's education framework was unsuccessful not mainly because of weak political commitment, but due to the fact that the legal standards controlling education during crises lacked enforceability. Under Article 13 of the ICESCR and its translation in General Comment Number 13, Sub-Saharan Africa countries were mandated to provide the accessibility, and non-discrimination of education, even during crises.

However, widespread school closings without efficient alternatives ignored the standards of accessibility, especially for rural and low-income children. While UNESCO, on the other hand, using the Education 2030 framework and the Incheon Declaration, was required with tasks to support states with coordination, technical help, and international collaboration, its goal remained advisory compared to compulsory.

The invisibility of binding emergency education laws, enforceable mechanisms, and mandated international help meant that states could legally comply with duties under the international law while failing to provide equal access in practice. The Kenyan and Sub-Saharan African experience hence provides the structural limits of soft-law governance in attaining legally recognized education obligations during crises.

II. COVAX

The COVAX initiative was designed as a global coordination mechanism to ensure fair distribution of COVID-19 vaccines regardless of income level through systems such as the COVAX Facility, the COVAX Advance Market Commitment (AMC), and the humanitarian buffer. The Gavi COVAX AMC presents the AMC as a financial mechanism intended to ensure production capacity and supply for lower-income countries by leveraging participation and receiving payments from higher-income economies within the COVAX Facility. This source shows the perspective of a global health organization involved in coordination and focuses on manufacturing scale, advance purchase agreements, and readiness support for AMC-eligible countries ("The Gavi COVAX AMC Explained" 2021). The COVAX AMC functioned as the primary system for distributing vaccines to 92 low and middle-income economies through donor-funded support. The European Parliament briefing explains that the COVAX Facility served as a central purchasing office for self-financing economies, including the EU and its Member States. This document reflects a developed nation's perspective by emphasizing EU policies, European institutions' budgetary contributions, and the role of Team Europe as a major donor and exporter within COVAX. ("Understanding COVAX: The EU's Role in Vaccinating the World against Covid-19 | Think Tank | European Parliament" 2022) The NIH Globalization and Health article also describes the COVAX Facility and AMC focus on allocation systems such as the fair allocation mechanism, dose sharing principles, and participation across 177 countries, divided between self-financing and AMC-eligible economies. (de Bengy Puyvallée and Storeng 2022) Although the authors are affiliated with institutions in developed nations, the document adopts a global health perspective by examining how procurement allocation and donation practices shaped vaccine distribution across developed and developing countries. The WHO G20 Indonesia report establishes COVAX within broader multilateral efforts involving WHO UNICEF Gavi and the Access to COVID-19 Tools (ACT) Accelerator. It also describes policies such as the AMC, the humanitarian buffer fair allocation targets and delivery partnerships aimed at increasing coverage in low income and low coverage countries. This report reflects a multilateral and G20 perspective by addressing self-financing donor nations and lower-income recipient countries while framing vaccine distribution as part of global health security and economic recovery (World 2025).

The NIH sources describe COVAX as failing to guarantee equal vaccine access because distribution outcomes continued to follow national wealth rather than universal need across developed and developing countries. It lacked legal power to force developed nations to distribute vaccines to developing nations, as



supplies depended largely on donations and wealthier states engaged in vaccine nationalism. In this case, national self-interest represents the strongest limiting factor, as wealthy nations were legally allowed to prioritize domestic vaccination through advance purchase agreements. Cioffi states that rich industrialized nations such as Canada, the USA, the UK, Australia, the EU, and Japan pre-ordered the majority of available doses, which allowed early access for these countries (Cioffi and Cioffi 2021). In contrast, COVAX and low-income countries faced delayed coverage with widespread vaccination in some regions projected after 2023. The second article characterizes COVAX as a vaccine charity operating within the pharmaceutical market and notes that wealthy countries led by the United States participated through charitable contributions while prioritizing bilateral vaccine diplomacy (Sparke and Levy 2022). By June 2021, only 89 million doses had been distributed, which was less than 5 percent of the 2 billion dose target. At this time, vaccination rates in many African countries still remained below 2 percent. This shows that organizations managing vaccine supply did not fully adopt effective measures and lacked sufficient resources to deliver adequate amounts of vaccines to developing countries. Similarly, the third source argues that COVAX relied on voluntary donations and redistribution rather than scaling up manufacturing which allowed high income countries to tie up global supply through bilateral deals while 67 low income countries depended on COVAX and in the first year high income countries reached vaccination rates of 75 to 80 percent compared to less than 10 percent in low income countries with African countries receiving only 18.2 million of the 66 million doses expected. (Pilkington, Keestra, and Hill 2022) Financially, COVAX was disadvantaged by its dependence on donation and delayed fundings, while high-income countries secured supply early in the stage. The fourth source identifies vaccine nationalism as the primary challenge and explains that COVAX allowed self financing countries to procure doses for up to 50 percent of their populations while AMC countries were limited to 20 percent and by December 2021 COVAX delivered less than 50 percent of its 2 billion dose target with only 819 million doses reaching AMC countries out of 9.25 billion doses administered globally and this review reflects a global perspective with authors from India and Canada (Pushkaran, Chattu, and Narayanan 2023). Thus, the statistics during the COVID-19 pandemic demonstrate that measures adopted by COVAX failed to provide equal vaccine access across nations, mainly due to national self-interest and bilateral agreements caused by weak institutional authority.

Recommendations

I. Introduce regulations for emergency education situations

UNESCO should collaborate with UN states to focus only on consulting frameworks and create obligatory minimum norms for education consistency during worldwide crises, especially in low-income countries. The UNESCO case studies from the Sub-Saharan African region during the crisis shows that the invisibility of legal duties made states available to stop education for longer periods of time with no need to give reasonable options. While UNESCO's Education 2030 Framework and the Incheon Declaration highlight inclusivity and fairness, both documents do not need countries to continue the at-most access to education during emergencies. Implementing emergency education laws through a new Optional Protocol to the ICESCR, utilized by the UN Committee on Economic, Social and Cultural Rights and adopted by UN member states, would eventually decrease dependence on voluntary compliance by creating new binding obligations for education being prolonged during crises and improve accessibility, especially in developing nations.

II. Create an Emergency Education Funding Mechanism Linked to UNESCO and Multilateral Banks

A major vulnerability seen during the pandemic was the inability to provide emergency funding to discuss digital device gaps, teacher trainings, and remote learning access in poorer states. UNESCO should support for a legally defined sudden education funding mechanism created through a combined agreement between UNESCO, the World Bank, and regional development banks, funded by required crisis-time involvements from high-income states and pre-existing worldwide education funds. This technique would suddenly start financing during global emergencies to advocate for internet access, device expansion, remote-based learning, and teacher-filled building in dismantled environments. According to UNESCO's



Sub-Saharan education frameworks, slowdowns in emergency funding continue school closures and learning loss, therefore strengthening pre-existing educational disparities compared to alleviating them.

III. Enforcing monitoring and reporting requirements under the goal of quality education

UNESCO should strengthen the reporting techniques correlated with SDG 4 by mandating countries to collect not only registration and graduation rates, but also digital availability, crisis readiness, and education identifiers. During COVID-19, several governments officially acknowledged their goal to education while failing to reveal the scale of education failure and exclusion. Enforced, standardized reporting, based on agreed SDG 4 crisis indicators such as digital access, instructional time lost, and student involvement, needs to be achieved by states, independently certified by UNESCO and partner agencies, and disaggregated by wealth, gender, region, and ethnicity to stop data manipulation and provide accountability. This approach correlates with the findings from the World Bank and UNESCO frameworks emphasizing the absence of verified data as an essential safety barrier to a more welcoming education.

IV. Burdens on developed countries

The WHO should impose binding burdens on developed countries during global health crises such as the COVID-19 pandemic. There should be an international law determining mandatory vaccine dose-sharing quotas to maximize numbers of vaccine secured and donations from developed countries based on their economies. Furthermore, financial penalties or contribution requirements for hoarding vaccines and creating bilateral arguments for economic interests could prevent the countries from overpurchasing vaccines. Separate regulatory obligations limiting advance purchase agreements beyond domestic needs could also help wealthy nations to comply. Amendments to existing international legal frameworks such as the IHR would address the legal gap. A treaty-based obligation that requires developed countries to transfer a fixed percentage of vaccine output by the WHO could enhance compliance. However, the system should also incorporate conditional exceptions after carefully assessing each country's financial status and economy. Politically, this would require reframing vaccine equity as a matter of global security rather than charity. This would reduce vaccine nationalism and ensure that mechanisms like COVAX function as an equal distribution system.

V. Regional negotiations rather than International-level negotiations

Rather than relying on universal participation through international institutions such as the WHO, international vaccine governance should include regional agreements that impose stronger compliance. Since international institutions such as WHO emphasize the importance of equality among countries, it is hard for these institutions to impose mandatory rules that could face backlashes. Regional agreements would impose stronger compliance expectations among smaller groups of states. They would allow peer pressure and reciprocal enforcement, especially effective in a time where disease spread quickly. For example, the African Union's African Vaccine Acquisition Trust coordinated vaccine distribution among African states, accelerating vaccine access for low-income states that otherwise would have been delayed. Thus, it is important to group states into regional agreements within neighboring states.

VI. Use other legal authority to pressure developed countries (G20)

Especially during the time of emergency, it is important to ensure binding and clear rules strengthened by a central authority. Vaccine inequity is tied to global supply chains and these are areas where institutions like the G20 exert influence. The G20 could condition economic cooperation or trade facilitation on participation in equitable vaccine distribution and coordinate collective limits on advance purchase agreements. They could also advocate legally binding obligations for each country and later incorporate into the WHO. This recognizes that legal power already exists outside traditional health law frameworks. Using economic pressure would help developed states respond to legal obligations and recognize global health crises as widespread challenges that could affect everyone. This would address the weak institutional power backed by other powerful nation leagues or organizations.



Conclusion

The COVID-19 pandemic showed limitations in international legal frameworks managing access to vaccines and education. Although institutions such as the WHO and UNESCO recognize these resources as public goods, their legal framework based on voluntary cooperation and non-binding rules discouraged equitable outcomes during the COVID-19 pandemic. Developed countries were able to prioritize national self-interests through hoarding vaccines and stronger digital education infrastructures without violating international law. The literature review and case studies show that these disparities were increased by pre-existing structural inequalities between developed and developing states. Initiatives such as COVAX and the Education 2030 Framework lacked enforcement mechanisms and emergency financing to address resource scarcity. Consequently, international institutions were unable to enforce compliance and prompt equitable access. This research shows that international law was unable to ensure equitable access to education and vaccines during the pandemic.

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References

- (1) Sampath, S.; Khedr, A.; Qamar, S.; Tekin, A.; Singh, R.; Green, R.; Kashyap, R. Pandemics Throughout the History. *Cureus* 2021, 13 (9), e18136. <https://doi.org/10.7759/cureus.18136>.
- (2) UNCTAD. 2025. "UNCTADstat - Classifications." [unctadstat.unctad.org](https://unctadstat.unctad.org/EN/Classifications.html). 2025. <https://unctadstat.unctad.org/EN/Classifications.html>.
- (3) UNESCO. 2006. "Universal Declaration on Bioethics and Human Rights." [Unesco.org](https://unesdoc.unesco.org/ark:/48223/pf0000146180). UNESCO. 2006. <https://unesdoc.unesco.org/ark:/48223/pf0000146180>.
- (4) United Nations Educational, Scientific, and Cultural Organization (UNESCO). Global Education Monitoring Report 2020: Inclusion and Education - All means All. Paris: UNESCO, 2020.
- (5) Lennox, Janet, Nicolas Reuge, and Francisco Benavides. 2021. "UNICEF's Lessons Learned from the Education Response to the COVID-19 Crisis and Reflections on the Implications for Education Policy." *International Journal of Educational Development* 85 (May): 102429. <https://doi.org/10.1016/j.ijedudev.2021.102429>.
- (6) "HUMAN RIGHTS and ACCESS to COVID-19 VACCINES OVERVIEW." 2020 https://www.ohchr.org/sites/default/files/Documents/Events/COVID-19_AccessVaccines_Guidance.pdf.
- (7) Phelan, Alexandra L, Mark Eccleston-Turner, Michelle Rourke, Allan Maleche, and Chenguang Wang. 2020. "Legal Agreements: Barriers and Enablers to Global Equitable COVID-19 Vaccine Access." *The Lancet* 396 (10254): 800–802. [https://doi.org/10.1016/s0140-6736\(20\)31873-0](https://doi.org/10.1016/s0140-6736(20)31873-0).
- (8) Halabi, Sam, and Ana Santos Rutschman. 2021. "Viral Sovereignty, Vaccine Diplomacy, and Vaccine Nationalism: The Institutions of Global Vaccine Access." *SSRN Electronic Journal* 36 (1). <https://doi.org/10.2139/ssrn.3902809>.



- (9) "Inequitable by Design: The Patent Culture, Law, and Politics behind COVID-19 Vaccine Global Access - Michigan Journal of Law Reform." 2023. Michigan Journal of Law Reform. July 3, 2023. <https://mjlr.org/journal/inequitable-by-design/>.
- (10) Berna Akcali Gur, and Joanna Kulesza. 2024. "Equitable Access to Satellite Broadband Services: Challenges and Opportunities for Developing Countries." Telecommunications Policy, March, 102731–31. <https://doi.org/10.1016/j.telpol.2024.102731>.
- (11) Suneth Agampodi, Ondari D Mogeni, Rebecca Chandler, Megha Pansuriya, Jerome H Kim, and Jean-Louis Excler. 2024. "Global Pandemic Preparedness: Learning from the COVID-19 Vaccine Development and Distribution." Expert Review of Vaccines, August. <https://doi.org/10.1080/14760584.2024.2395546>.
- (12) WHO. 2020. "COVAX: Working for Global Equitable Access to COVID-19 Vaccines." World Health Organization. 2020. <https://www.who.int/initiatives/act-accelerator/covax>.
- (13) "WHO Pandemic Agreement." 2025. https://apps.who.int/gb/ebwha/pdf_files/WHA78/A78_R1-en.pdf.
- (14) World Health Organisation. 2025. "World Health Assembly Adopts Historic Pandemic Agreement to Make the World More Equitable and Safer from Future Pandemics." Who.int. World Health Organization: WHO. May 20, 2025. <https://www.who.int/news/item/20-05-2025-world-health-assembly-adopts-historic-pandemic-agreement-to-make-the-world-more-equitable-and-safer-from-future-pandemics>.
- (15) Lazaro, Lorente, Luis Miguel, Ana Ancheta Arrabal, and Cristina Pulido-Montes. "The Right to Education and ICT during COVID-19: An International Perspective." Sustainability 12, no. 21 (2020): 9091.
- (16) <https://www.mdpi.com/2071-1050/12/21/9091>
- (17) United Nations Committee on Economic, Social and Cultural Rights. General Comment No. 13: The Right to Education (Article 13 of the Covenant). UN Doc. E/C.12/1999/10. 1999.
- (18) United Nations Educational, Scientific, and Cultural Organization (UNESCO). Right to Education Handbook: International Legal Recognition of the Right to Education. Chapter 2. Cham: Springer, 2021.
- (19) United Nations Educational, Scientific, and Cultural Organization (UNESCO). Education in a Post-COVID World: Nine Ideas for Public Action. Paris: UNESCO, 2020.
- (20) World Health Organization. COVAX: Working for Global Equitable Access to COVID-19 Vaccines. Geneva: WHO, 2021.
- (21) Burnett, Nicholas. "The International Architecture for Education: Some Reflections." International Journal of Educational Development 40 (2015): 15-24.
- (22) UNESCO. "Education 2030 Framework for Action to Be Formally Adopted and Launched." UNESCO.org, October 31, 2015, last updated January 18, 2024. <https://www.google.com/url?q=https://www.unesco.org/en/articles/education-2030-framewo>
- (23) Burnett, Nicholas. 2015. "The International Architecture for Education: Some Reflections." International Journal of Educational Development 40: 15-24.



- (24) Government of Kenya. 2019. Education Sector Report. Nairobi: Ministry of Education.
- (25) Lázaro, Luis Miguel, Ana Ancheta Arrabal, and Cristina Pulido-Montes. 2020. "The Right to Education and ICT during COVID-19: An International Perspective." *Sustainability* 12 (21): 9091. <https://www.mdpi.com/2071-1050/12/21/9091>
- (26) ScienceDirect. 2021. "Learning Losses during COVID-19 School Closures in Sub-Saharan Africa." *International Journal of Educational Development* 85: 102429. <https://www.sciencedirect.com/science/article/pii/S0738059321000821?via%3Dihub>
- (27) UNESCO. 2015. Education 2030: Incheon Declaration and Framework for Action. Paris: UNESCO
- (28) UNESCO. 2020a. Education in a Post-COVID World: Nine Ideas for Public Action. Paris: UNESCO
- (29) UNESCO. 2020b. Global Education Monitoring Report 2020: Inclusion and Education-All Means All. Paris: UNESCO
- (30) UNESCO. 2021. Right to Education Handbook: International Legal Recognition of the Right to Education. Cham: Springer
- (31) World Bank. 2020. The Challenge of Inclusive Education in Sub-Saharan Africa. Washington, DC: World Bank Group
- (32) "The Gavi COVAX AMC Explained." n.d. [Www.gavi.org](https://www.gavi.org). <https://www.gavi.org/vaccineswork/gavi-covax-amc-explained>.
- (33) "Understanding COVAX: The EU's Role in Vaccinating the World against Covid-19 | Think Tank | European Parliament." 2022. [Europa.eu](https://www.europa.eu). 2022. [https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI\(2022\)729319](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)729319).
- (34) Bengy Puyvallée, Antoine de, and Katerini Tagmatarchi Storeng. 2022. "COVAX, Vaccine Donations and the Politics of Global Vaccine Inequity." *Globalization and Health* 18 (1). <https://doi.org/10.1186/s12992-022-00801-z>.
- (35) World. 2025. "Accelerating COVID-19 Vaccine Deployment : Removing Obstacles to Boost Coverage Levels and Protect Those at High-Risk." World Bank. 2025. <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099352004212214271>.
- (36) Cioffi, A., and F. Cioffi. 2021. "COVID-19 Vaccine: Risk of Inequality and Failure of Public Health Strategies." *Ethics, Medicine and Public Health* 17 (June): 100653. <https://doi.org/10.1016/j.jemep.2021.100653>.
- (37) Sparke, Matthew, and Orly Levy. 2022. "Competing Responses to Global Inequalities in Access to COVID Vaccines: Vaccine Diplomacy and Vaccine Charity versus Vaccine Liberty." *Clinical Infectious Diseases* 75 (1). <https://doi.org/10.1093/cid/ciac361>.
- (38) Pilkington, Victoria, Sarai Mirjam Keestra, and Andrew Hill. 2022. "Global COVID-19 Vaccine Inequity: Failures in the First Year of Distribution and Potential Solutions for the Future." *Frontiers in Public Health* 10 (10). <https://doi.org/10.3389/fpubh.2022.821117>.



(39)Pushkaran, Anjali, Vijay Kumar Chattu, and Prakash Narayanan. 2023. "A Critical Analysis of COVAX Alliance and Corresponding Global Health Governance and Policy Issues: A Scoping Review." *BMJ Global Health* 8 (10): e012168. <https://doi.org/10.1136/bmjgh-2023-012168>.

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Retrosynthetic Analysis of Compound 13 from *Rhizopus* sp. W23

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Abstract

Compound 13 from *Rhizopus* sp. W23 is a recently discovered molecule in the deep sea, with a C₂₅ steroid structure and possessing an unusual 7/7/6/5 tetracyclic structure bicyclo [4.4.1] scaffold. This structure significantly deviates from the conventional canonical cyclopentanoperhydrophenanthrene, and no complete retrosynthetic analysis for this molecule has been reported in the literature. A recent study suggests that this compound has the potential to treat osteoporosis by inhibiting adipogenic differentiation and osteoblast mineralization, albeit with moderate toxicity. In this work, a detailed retrosynthetic pathway of compound 13 is proposed by identifying key disconnections, strategic intermediates, and synthetic equivalents.

Keywords

Retrosynthesis; *Rhizopus* sp. W23; Compound 13; Osteoporosis; Natural Product

Introduction

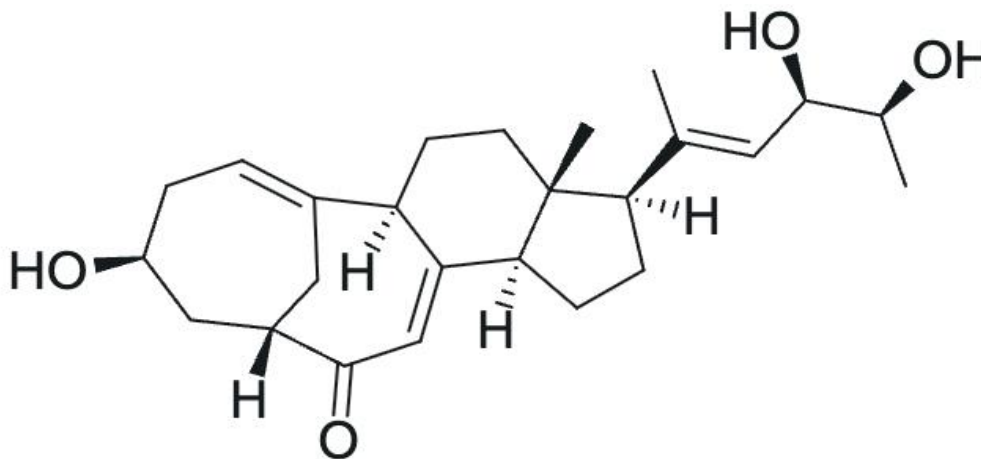


Figure 1. Compound 13 Extracted from *Rhizopus* sp. W23

Natural products extracted from extreme environments can often be a source for discovering diverse compounds, with their structure being not only novel but also unique. One such example is molecule 13 extracted from *Rhizopus* sp. W23, with the molecular formula C₂₅H₃₈O₄ and an Mr of 402.6 g/mol (Figure 1) (Wang et al., 2015). The fungus *Rhizopus* sp. W23 was found in the deep sea, which is predominantly characterized by high pressure, low temperatures, oligotrophic conditions, and minimal light exposure. Among the diverse inhabitants in the deep sea, the fungi of the genus *Rhizopus* have been recently recognized to have bioactive secondary metabolites. While *Rhizopus* species is often associated with connections to terrestrial environments, such as bread molds, *Rhizopus* sp. W23 is a significant deviation



from the common perception: *Rhizopus* sp. W23 was found in the deep sea at depths exceeding 1000 meters (Wang et al., 2015; He et al., 2022). The adaptation of the fungi to the extreme environment has allowed the development of distinctive biosynthetic gene clusters and secondary metabolites, which are often absent in terrestrial environments (Wang et al., 2020; Zhao et al., 2022). In fact, more than 180 bioactive secondary metabolites were discovered from the deep-sea fungi with diverse effects, including anticancer, antimicrobial, antifungal, antiprotozoal, and antiviral activities (Wang et al., 2015).

The recent chemical investigation on *Rhizopus* sp. W23 allowed the discovery of one handling artifact and six new and 12 known cyclocitrinol analogues: that is, an unusual C²⁵ steroid natural product (Figure 1). Notably, these molecules present an unusual 7/7/6/5-tetracyclic scaffold bicyclo [4.4.1] ring system (He et al., 2022). In other words, the compounds are characterized by four rings that are fused, with each ring exhibiting 7, 7, 6, and 5 carbon atoms, respectively, with bicyclo [4.4.1] representing the number of carbon atoms in each of three bridges connecting the bridgehead atoms. This shows a significant deviation from the canonical cyclopentanoperhydrophenanthrene compound, a fundamental structural unit of steroids (Liu et al., 2018). To date, no complete retrosynthetic analysis for compound 13 has been proposed in the literature, making this investigation necessary. This novel structure of the compound presents a unique challenge in the synthesis but also presents a potential opportunity to be utilized in curing osteoporosis (He et al., 2022).

Osteoporosis is a non-communicable disease affecting the bones, caused by a decrease in the mineral density and mass of the bones (Pierce et al., 2019). At the cellular level, it arises from the molecular imbalance between osteoclasts, or the bone-resorbing cells, and osteoblasts, or the bone-forming cells (He et al., 2022). However, the newly discovered cyclocitrinol analogues, particularly compounds 13 and 19, have been shown to enhance the mineralization of the osteoblasts with moderate cytotoxicity while inhibiting adipogenic differentiation of bone marrow mesenchymal stem cells, or BMSCs, in vitro (He et al., 2022). That is, while the stem cells of osteoporotic patients transform into adipocytes, or fat cells, instead of bone cells, the compounds 13 and 19 can prevent this (He et al., 2022; Zhu et al., 2023). These activities indicate that compound 13 may have the potential to restore the formation of the bones in osteoporotic patients, specifically by shifting the differentiation balance toward bone formation rather than fat accumulation within the marrow. Importantly, these effects were observed at relatively low concentrations (5-20 μ M) (He et al., 2022). As a result, it suggests the possible development of an anti-osteoporosis cure from the newly identified molecule. However, it is important to note that the findings on the potential for anti-osteoporosis effects are based on in-vitro studies, suggesting that the therapeutic effects need to be further validated through clinical application. Therefore, its promise should be considered long-term rather than immediate. In fact, proposing a potential retrosynthetic pathway can possibly foster the production of sufficient quantities of the compound in order to further evaluate its biological potential and synthesize compounds with greater pharmacological properties.

Considering their marine origins, rare molecular structure, and positive bioactivity, the newly discovered compounds are a compelling case for retrosynthetic analysis, which could offer a method for synthesizing them in the lab, thereby facilitating future drug development. Thus, this paper seeks to analyze the structural features of compound 13, specifically, and propose a possible retrosynthetic pathway. Yet for clarity and consistency throughout this study, compound 13, which was extracted from *Rhizopus* sp. W23, is referred to as *Rhizopus* sp. W23-13.

Results and Discussion

Retrosynthetic Analysis

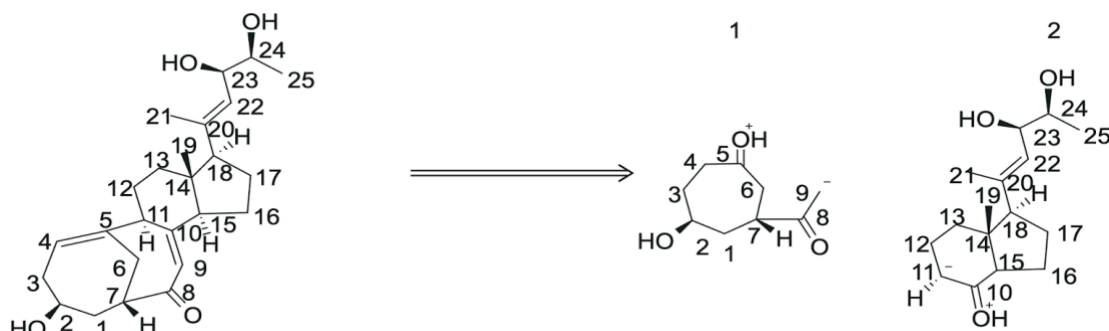


Figure 2. Key Retrosynthesis of *Rhizopus* sp. W23-13

In the retrosynthetic analysis of this molecule, a key disconnection was made between C4 = C5 and C9 = C10 (Figure 2). In the forward synthesis of compound 13, the transformation of the molecule can be observed through oxidation analysis: carbons C5 and C10 represent alcohol functionalities that may originate from nucleophilic addition to carbonyl precursors, while C4 and C9 correspond to reduced carbon centers. Therefore, the structure of compound 13 may potentially be constructed through two intramolecular carbon-carbon bond formation reactions through the nucleophilic attack at electrophilic carbonyl carbons based on the analysis.

Specifically, this reaction may include nucleophilic carbon species at C11 and C9 attacking electrophilic carbonyl carbons at C5 and C10, respectively. Although it is ideal for both reactions to occur simultaneously, allowing the bond formation to co-occur, this may not occur in reality due to steric and kinetic limitations. Therefore, a sequential step may be necessary.

If an attack by a carbon nucleophile at C9 on the carbonyl carbon C10 occurs first, the carbonyl undergoes nucleophilic addition to form an alkoxide intermediate, which yields a secondary alcohol as a result of protonation. This transformation eliminates the electrophilic characteristic of carbonyl carbon, decreasing the probability of further nucleophilic attack by influencing the reactivity of adjacent centers. Consequently, the bond formation between C11 and C5 becomes less favorable.

In contrast, if the bond formation between C11 and C5 occurs first, this reaction does not significantly impact the favorability of the reaction between C9 and C10, as there are minimal conjugative or inductive effects due to the distance between C5 and C9. Therefore, if a sequential step is required, the preferred sequence would be the initial formation of the bond between C11 and C, followed by the reaction between C9 and C10.

This disconnection was further supported as it produced two stable intermediates. Both compounds 1 and 2 have reactive centers positioned alpha to carbonyl groups, allowing stabilization through resonance.

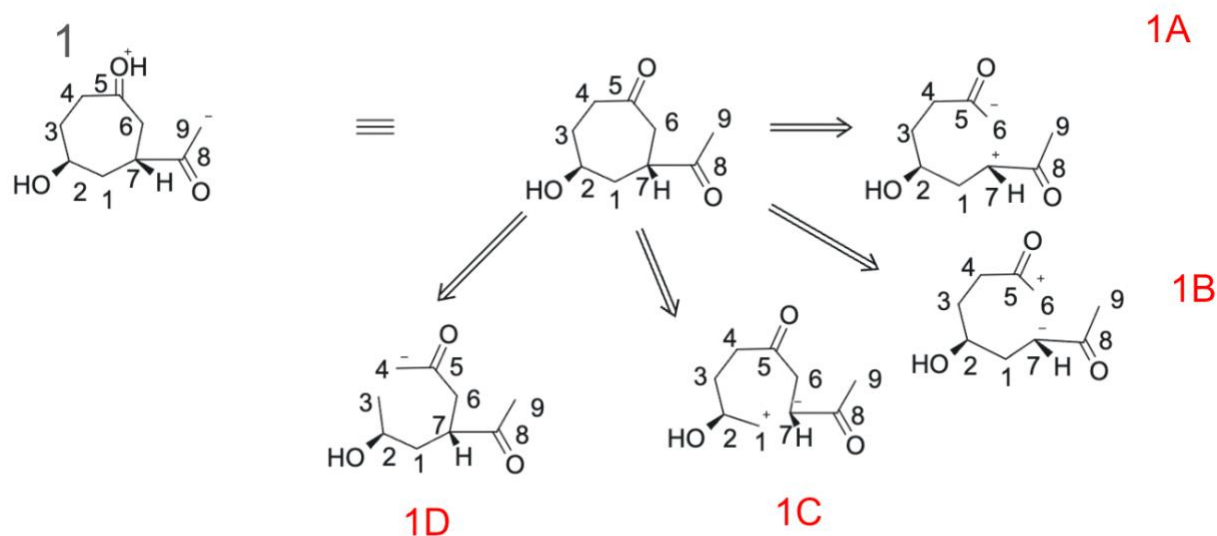


Figure 3. Possible Disconnections of Compound 1

Further retrosynthetic analysis focused on compound 1 as a next step. Four possible disconnection strategies of compound 1 were considered, with each approach including the cleavage of the bond in the 2,3 relationship relative to one of the two ketones (Fig. 3). Compounds 1A and 1B were derived by cleavage between two alpha carbons adjacent to the carbonyl groups. Although 1A and 1B have the same disconnection site, they present opposite charge assignments, which can be rationalized through enolate resonance structure. In contrast, compound 1C was created by the cleavage of the bond between the 2,3-relationship between the alpha and beta carbons relative to the carbonyl group attached to C8, while compound 1D involved the same pattern applied to the carbonyl group attached to C5.

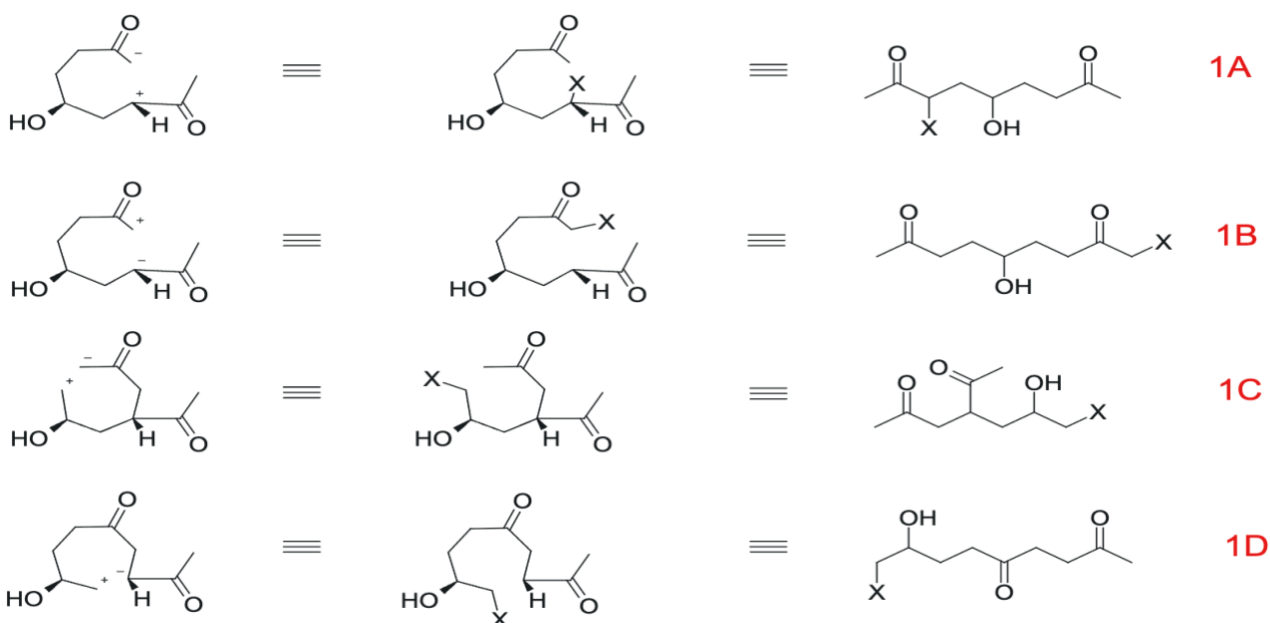


Figure 4. Linear Forms of Synthetic Equivalents

To evaluate each of these pathways, each compound was converted into its corresponding synthetic equivalents. In these representations, the electrophilic synthons were transformed into alkyl halides, as expressed in "X", while nucleophilic carbons in synthons were represented as neutral carbonyl-containing compounds, including enolate precursors (Fig. 4). As all disconnections involve the cleavage of the seven-membered ring system, the intermediates can be represented as linear chains, facilitating the comparison of synthetic availability through clear visualization.

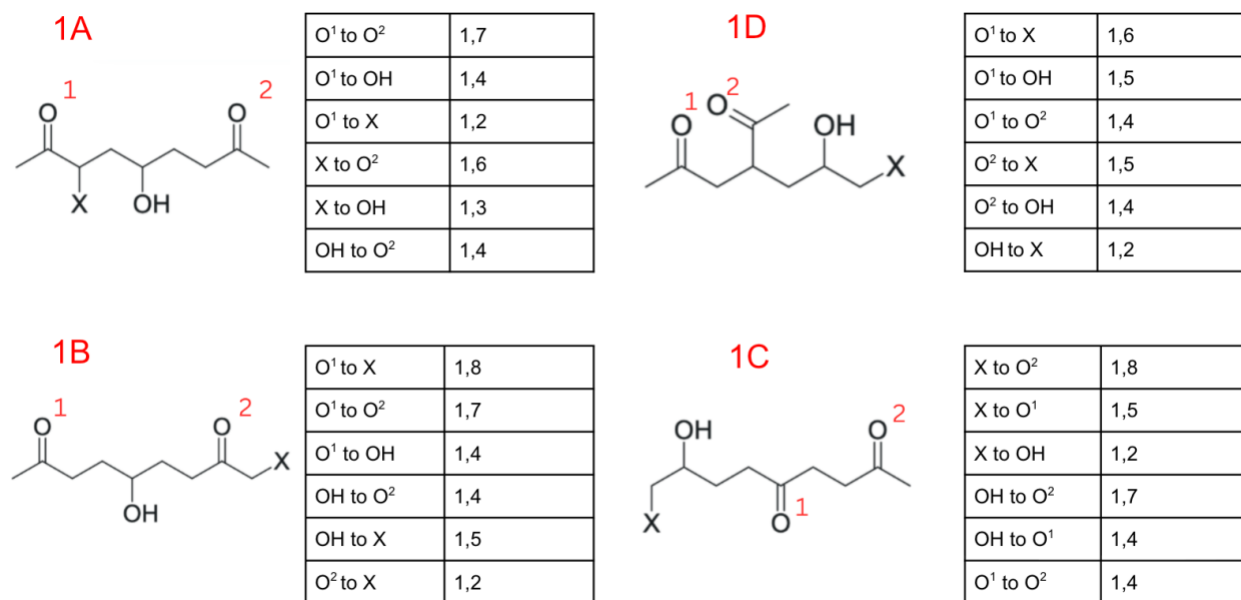


Figure 5. Dioxygenation Pattern Analysis

To further evaluate the feasibility of each method of disconnection, dioxygenation pattern analysis was conducted (Fig. 5). This analysis allows to identify 1,3 and 1,5 positions between oxygen-containing functional groups in the synthetic equivalents. These positions are crucial in identifying further disconnection sites due to the compatibility with established bond-forming reactions. In particular, 1,5-dicarbonyl systems are essential in intermediates, as they can form an intramolecular carbon-carbon bond through enolate-mediated reactions, including aldol condensations or cyclizations.

The two oxygens in each synthetic equivalent were assigned a number, either 1 or 2, for clarity and consistency. This analysis allowed an evaluation of the relative effectiveness of each possible disconnection strategy.

Through this analysis, it was discovered that pathways A, B, and C present only one favorable relationship of either of the two positions, while pathway D demonstrates two distinct 1,5 dioxygenation patterns. As the existence of two reactive sites increases the probability of successful cyclization, pathway D was selected as the most favorable disconnection strategy.

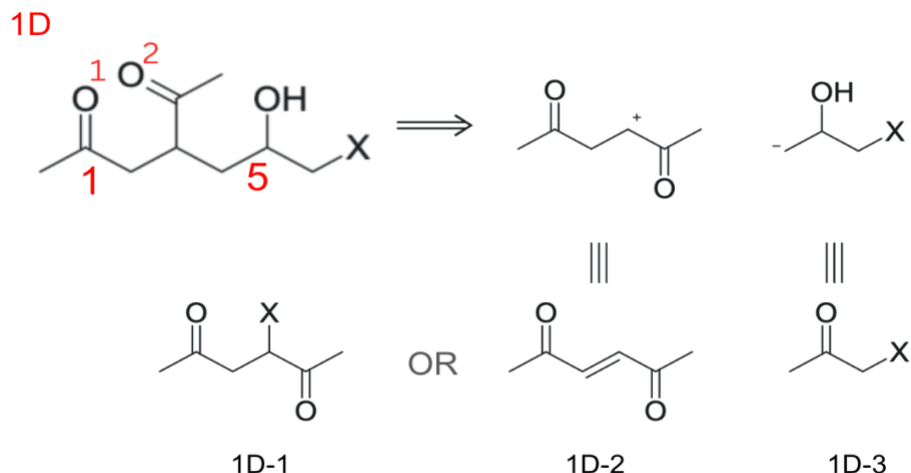


Figure 6. Synthetic Equivalents of Compound 1D

Within the synthetic equivalent 1D, two potential 1,5-disconnection sites were identified (Fig. 6). However, the disconnection between ketone 1 and alcohol functionalities was utilized instead of the 1,5 relationship between ketone 2 and the halide (Fig. 6). This allowed the disconnection between ketone 1 and the alcohol functionalities, specifically between the 3,4 positions relative to the carbonyl group. This disconnection leads to the formation of two separate compounds with complementary reactivity: one electrophilic and one nucleophilic.

In the subsequent representation of the corresponding synthetic equivalents of the two compounds, the electrophilic fragment can be represented as an alkyl halide or as an α,β -unsaturated carbonyl compound, while the nucleophilic fragment can be transformed into an enolate precursor derived from a ketone. As a result, this analysis leads to three potential compounds (1D-1, 1D-2, and 1D-3), which can form a carbon-carbon bond in appropriate conditions

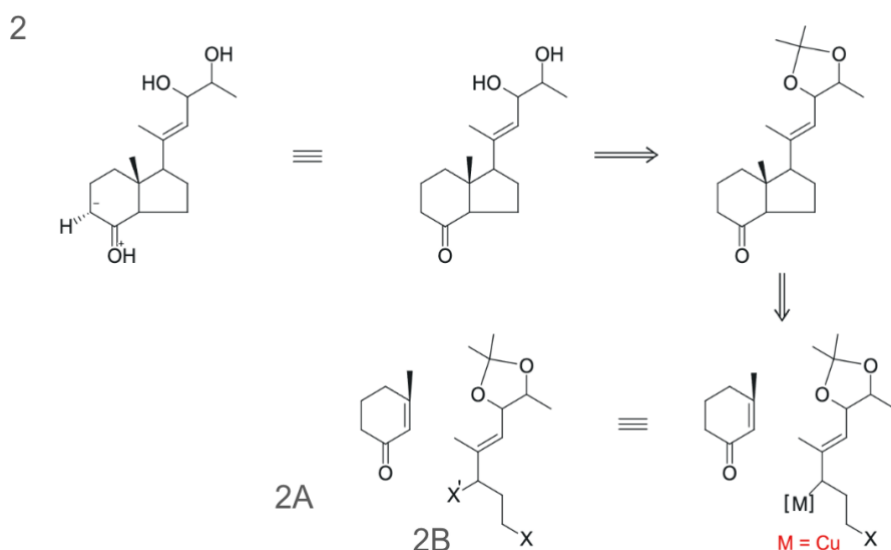


Figure 7. Retrosynthesis of Compound 2



The retrosynthesis of compound 2 (Fig. 7) was then theorized as compound 1 was fully disconnected. Firstly, the charged intermediate compound 2 was converted into its neutral synthetic equivalents by replacing protonated oxygen species with ketones and by removing the formal charge.

To prevent undesired side reactions during subsequent steps, the vicinal diol located at the side chain was converted to an acetonide as a protection through acid-catalyzed ketone formation with acetone. This transformation leads to the formation of a five-membered cyclic ketal, replacing the hydroxyl groups and enhancing the chemical stability of further reaction conditions.

Subsequently, the six-membered ring was disconnected from the rest of the compound, generating two separate compounds. This cleavage represents the use of an organocuprate reagent (Gilman reagent, R_2CuLi), which can undergo a selective 1,4-addition in the forward synthesis through nucleophilic addition to the β -carbon of α,β -unsaturated carbonyl compounds. Consequently, this disconnection yields the two synthetic equivalents: 2A and 2B.

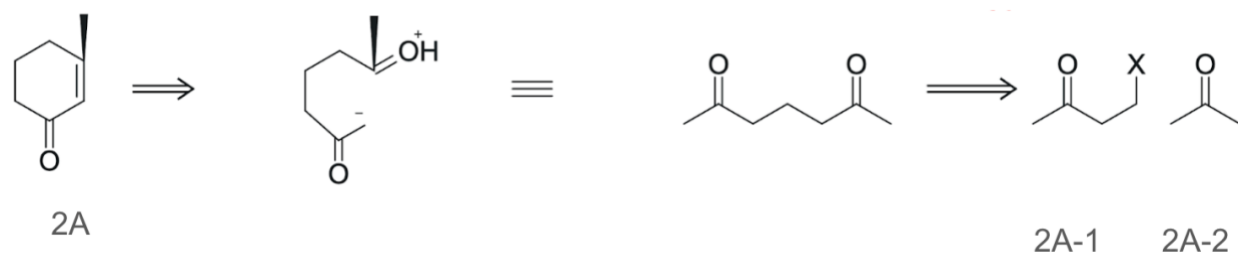


Figure 8. Retrosynthesis of 2A-1

As two separate compounds were generated, the retrosynthetic pathway of compound 2A was first considered (Fig. 8). The retrosynthetic analysis begins with the cleavage of the six-membered ring, which represents the reversal of an intramolecular carbon-carbon bond-forming reaction. The disconnection of the carbon double bond leads to the formation of a protonated oxygen atom with a double bond while assigning a negative charge on the opposite side of the ring. As this disconnection leads to the formation of the linear chain, the synthetic equivalent can be considered in the linear form, specifically forming a linear diketone system presenting a 1,5-dicarbonyl arrangement. The diketone arrangement is synthetically valuable, as it readily undergoes enolate-mediated cyclization reactions. Exploiting this feature, the chain can be further decoupled into simpler precursors: 2A-1 and 2A-2. These two compounds can be reconnected by establishing a carbon-carbon bond-formation reaction in the forward synthesis.

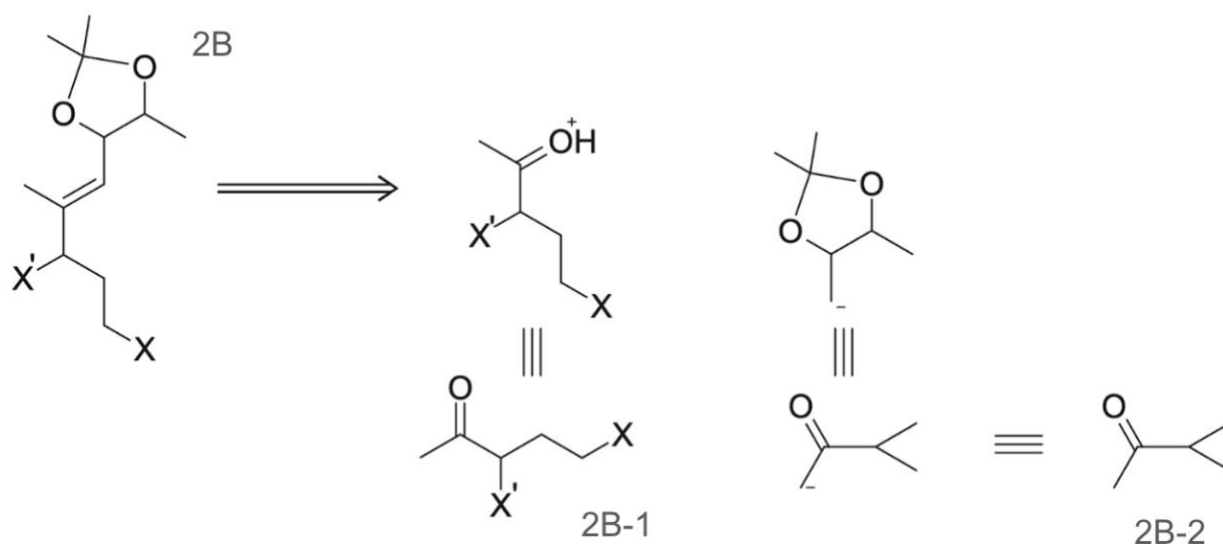


Figure 9. Retrosynthesis of Compound 2B

Subsequently, the retrosynthetic analysis of compound 2B was conducted (Fig. 9). As compound 2B involved a double bond between two carbon atoms, oxidation analysis can be utilized by considering the alkene functionality. Conceptual oxidative cleavage of the alkene would generate two carbonyl-containing fragments (ketones or aldehydes, depending on substitution). Disconnection of the alkene therefore reveals a carbonyl fragment on the alcohol-bearing side, with its synthetic equivalent representing a ketone, leading to the formation of the compound 2B-1. On the opposite side, the removal of a formal charge and the deprotection of the acetonide yield a fragment that contains a ketone, representing a tertiary carbon center. As a result, the compound 2B-2 could be further theorized.

Starting Materials of *Rhizopus* sp. W23-13

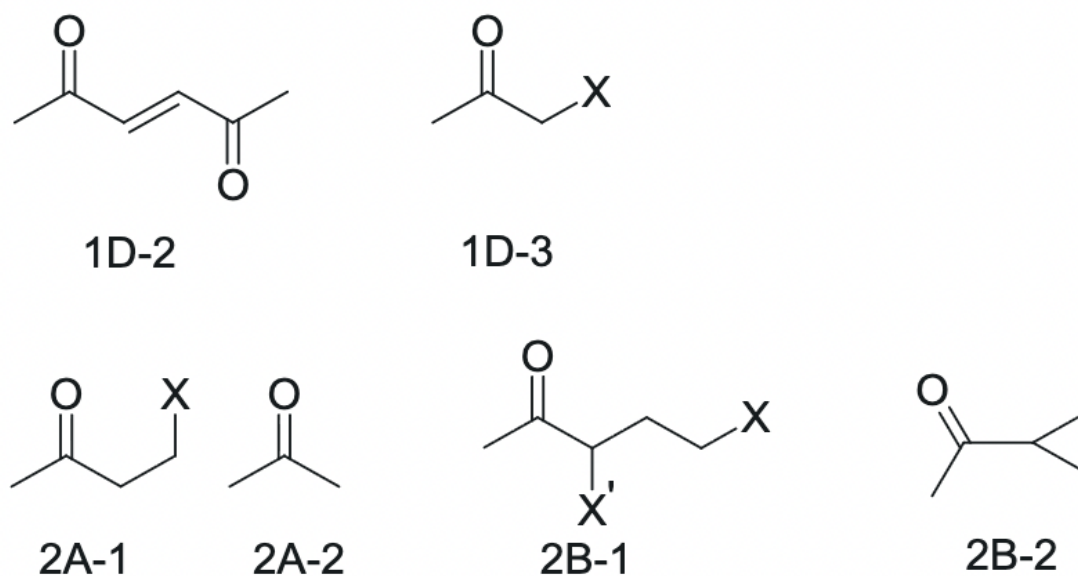


Figure 10. Theorized Synthesis of *Rhizopus* sp. W23-13



In summary, during the synthesis of *Rhizopus* sp. W23-13, a total of 6 key precursor molecules are required: 1D-2, 1D-3, 2A-1, 2A-2, 2B-1, and 2B-2. The synthetic pathway begins with the carbon-carbon bond formation reaction between 1D-2 and 1D-3 (or even 1D-1 and 1D-3), which undergo a reaction to generate the intermediate 1D. Although 1D-1 can also be utilized to react with 1D-3, 1D-2 may be preferred due to its symmetrical structure. In parallel, 2A-1 and 2A-2 undergo a carbon-carbon formation reaction to yield the intermediate 2A, while 2B-1 and 2B-2 act as precursors to form molecule 2B.

Once these intermediates are in place, the synthesis should proceed through sequential combination. Specifically, intermediates 2A and 2B should undergo a reaction to produce compound 2, which is a significant fragment of the target molecule.

Finally, the last step involves the convergent coupling of compounds 1 and 2, resulting in the production of the natural product, *Rhizopus* sp. W23-13. This step is especially essential as the two main compounds created from independent synthesis lead to the final product. This not only improves efficiency but also ensures that the structure of the compound is generated in a controlled pathway.

Discussion

Alternative Retrosynthetic Pathway

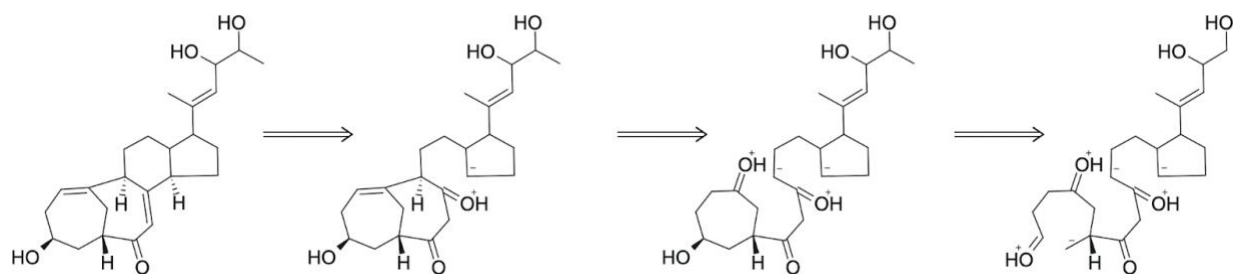


Fig 11. Alternative Retrosynthetic Pathway (Rejected)

An alternative retrosynthetic pathway was also considered during the retrosynthetic analysis (Fig. 11). The theorized basic mechanism of this retrosynthesis involves the disconnection across alkene and alcohol functionalities. However, this retrosynthesis pathway leads to intermediates with unstabilized carbanionic synthons. These species lack an adjacent electron-withdrawing group or resonance stabilization. As a result, this chemical structure is very likely to be highly unstable and synthetically unfavorable. In fact, no resonance nucleophilic precursors can be identified for these intermediates when converted into their synthetic equivalents. Therefore, it was concluded that the presence of isolated anions makes this retrosynthetic pathway infeasible and thus rejected.

Evaluation of Synthetic Feasibility

While most of the proposed retrosynthetic pathways are mostly feasible, the initial step of the retrosynthetic pathway (Fig. 2) creates a significant synthetic challenge, as it requires the cleavage of two bonds in the retrosynthesis, implying the formation of two carbon-carbon bonds in the forward synthesis. Therefore, a synthetic pathway with successive formation of bonds is likely to be more favorable.

During the synthesis of compound 13, it is more favorable for the reaction between C11 and C5 to occur prior to the bond formation between C9 and C10 as the C11-C5 reaction maintains the electrophilicity of the carbonyl functionality at C10 and prevents the loss of reactivity. However, if the bond formation between C9 and C10 occurs first, this reaction would lead to a reduction in the electrophilicity of this site and prevent subsequent reaction between C11 and C5.



Although challenges such as conformational rigidity, geometric strain, and competing side reactions may be potentially possible, this pathway remains plausible based on mechanistic and electronic considerations.

Impacts & Future Directions

The retrosynthesis proposed herein is the first published retrosynthetic analysis. As the global burden of osteoporosis constantly increases, reaching 41.5 million cases in 2019, and causes fracture-related disabilities, it is essential to develop a novel treatment for osteoporosis. (Zhu et al., 2023) While existing treatments for osteoporosis predominantly focus on inhibiting the differentiation of osteoclasts, the newly found compound can enhance the formation of the bond by fostering osteoblast activity with moderate side effects. (He et al., 2022) This highlights that it could potentially become the leading material for anti-osteoporosis.

Further research should focus on the experimental validation of the proposed pathway of the retrosynthesis through laboratory synthesis. At the same time, researching alternative synthetic strategies of *Rhizopus* sp. W23-13 is also important in order to identify more efficient and sustainable methods for the (retro)synthetic pathway. Upon successful synthesis, experiments on preclinical in vitro cell models and in vivo models should also be conducted in order to foster its therapeutic potential.

Conclusion

The retrosynthesis of *Rhizopus* sp. W23-13 provides a possible pathway to break down the complex tetracyclic structure into simpler synthetic equivalents. The analysis provides key disconnections and a protective strategy that could allow laboratory synthesis of the compound. Given its ability to enhance osteoblast activity and prevent adipogenic differentiation of BMSCs, *Rhizopus* sp. W23-13 presents its potential as a novel candidate for anti-osteoporosis.

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References

- He, Z.-H., Xie, C.-L., Wu, T., Yue, Y.-T., Wang, C.-F., Xu, L., Xie, M.-M., Zhang, Y., Hao, Y.-J., Xu, R., & Yang, X.-W. (2022). Tetracyclic Steroids Bearing a Bicyclo[4.4.1] Ring System as Potent Antiosteoporosis Agents from the Deep-Sea-Derived Fungus *Rhizopus* sp. W23. *Journal of Natural Products*, 86(1), 157–165. <https://doi.org/10.1021/acs.jnatprod.2c00866>
- Liu, J., Wu, J., Fan, J.-H., Yan, X., Mei, G., & Li, C.-C. (2018). Asymmetric Total Synthesis of Cyclocitrinol. *Journal of the American Chemical Society*, 140(16), 5365–5369. <https://doi.org/10.1021/jacs.8b02629>
- Pierce, J. R., Begun, D. L., Westendorf, J. J., & McGee-Lawrence, M. E. (2019). Defining osteoblast and adipocyte lineages in the bone marrow. *BONE*, 118, 2–7. <https://doi.org/10.1016/j.bone.2018.05.019>
- Wang, Y.-N., Meng, L.-H., & Wang, B.-G. (2020). Progress in Research on Bioactive Secondary Metabolites from Deep-Sea Derived Microorganisms. *Marine Drugs*, 18(12), 614. <https://doi.org/10.3390/md18120614>
- Wang, Y.-T., Xue, Y.-R., & Liu, C.-H. (2015). A Brief Review of Bioactive Metabolites Derived from Deep-Sea Fungi. *Marine Drugs*, 13(8), 4594–4616. <https://doi.org/10.3390/md13084594>



Zhao, G., Tang, W., Zhang, J., Shi, P., Li, Y., Wang, J., Shen, Q., Si, H., Jiang, L., Yu, X., Zhu, H., Chen, G., Zhang, X., & Jia, H. (2022). Deep-Sea-Derived Fungi as Valuable Producers of Cytotoxic Secondary Metabolites and Their Leads Potential. *Frontiers in Marine Science*, 9. <https://doi.org/10.3389/fmars.2022.929561>

Zhu, Z., Yu, P., Wu, Y., Wu, Y., Tan, Z., Ling, J., Ma, J., Zhang, J., Zhu, W., & Liu, X. (2023). Sex Specific Global Burden of Osteoporosis in 204 Countries and Territories, from 1990 to 2030: An Age-Period-Cohort Modeling Study. *The Journal of Nutrition, Health and Aging*, 27(9), 767–774. <https://doi.org/10.1007/s12603-023-1971-4>

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PLAYING THE ODDS: AGENTIC LLMS FOR REAL-TIME NBA FORECASTING AND MARKET BETTING

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Abstract

Predicting the outcomes of professional basketball games is a challenging problem due to the intrinsic stochastic uncertainty of sports competitions and the heterogeneity of relevant information sources. While existing approaches in sports analytics primarily rely on structured historical statistics, such methods often struggle to incorporate timely and unstructured information. In this paper, we propose a unified framework that leverages large language models for probabilistic forecasting and decision making for NBA games and their prediction markets. Our approach combines specialized information retrieval agents with multiple role-based LLM predictors, whose forecasts are aggregated into the final forecasting probabilities. These probabilities are then operationalized through a fractional Kelly betting strategy in binary prediction markets. We evaluate the proposed system using both Brier Scores and simulated market returns, demonstrating that LLM-based forecasting can effectively complement traditional models and translate predictive improvements into economic values. Overall, our results demonstrate the potential of LLMs and in-context learning as flexible tools for decision-oriented sports analytics.

Keywords

Sports analytics, large language models, Game prediction

Introduction

Predicting the results of professional sports games has long been a central problem in sports analytics, with its applications ranging from coaching strategy to betting markets. However, as the volume and complexity of game-related data have increased, the limitations of traditional forecasting approaches have become evident. Early sports sciences and analytics relied heavily on the expertise of coaches and analysts, with competition data primarily being collected and interpreted manually (Ozkan 2020; Horvat et al. 2023). And while this was effective in small-scale settings, such approaches struggled to scale up as data volume grew, often resulting in incomplete utilization of the available information and limited predictive accuracy (Zhao, Du, and Tan 2023).

Advancements in computing power and data infrastructure initially enabled the adoption of machine learning (ML) techniques in sports analytics. In the NBA, researchers have explored a wide range of models, including naive bayes, artificial neural networks, and decision tree models (Thabtah, Zhang, and Abdelhamid 2019), achieving varying degrees of success in predicting the outcome of games (Tax and Joustra 2015; Pathak and Wadhwa 2016). Despite methodological diversity, state-of-the-art models typically report predictive accuracies in the range of approximately 67% to 75% (Gumm, Barrett, and Hu 2015; Kim, Magnusen, and Jeong 2023), suggesting both meaningful gains over heuristic baselines and persistent limits to purely data-driven performance in a highly stochastic environment.



More recently, progress in natural language processing has substantially expanded the scope of machine learning methods, particularly through the emergence of large language models (LLMs). Built on transformer architectures, LLMs are trained on massive corpora of text drawn from heterogeneous sources, enabling them to capture rich, semantic, contextual, and relational patterns in language. Rapid improvements in computational resources, model scale, and training data have led to dramatic gains in LLM performance across a wide range of different tasks (Wei et al. 2022). These advances have been most visible through interactive systems such as OpenAI's ChatGPT, which expose LLM capabilities through open-ended prompt-completion interfaces. In contrast to traditional machine learning pipelines that require carefully engineered numeric features, LLM-based approaches operate directly on unstructured text, therefore bypassing explicit feature construction and allowing flexible adaptation to diverse prediction problems (Liu et al. 2023).

An additional strength of LLMs lies in their ability to perform in-context learning. By conditioning on a small number of task-specific examples provided at inference time, LLMs can approximate task-specific behavior without parameter updates or retraining. Techniques such as few-shot prompting have been shown to generate robust performance across domains, even when labeled training data are scarce or costly to obtain (Brown et al. 2020). These properties suggest that LLMs provide a promising alternative to conventional numerical models, particularly in settings where relevant predictive information is embedded in textual, qualitative, or rapidly evolving sources.

Motivated by these developments, we explore whether large language models can be leveraged to improve probabilistic forecasting of NBA game outcomes by incorporating information sources that are largely inaccessible to traditional numerical models. Unlike prior basketball prediction studies that rely almost exclusively on structured historical statistics, our approach exploits timely and unstructured textual information, including injury reports, news coverage, and media content surrounding upcoming games. We design a unified LLM-based forecasting framework in which external information is first collected by specialized search agents and then synthesized by multiple role-specific predictors through prompt-based inference. By providing recent contextual evidence and, where appropriate, illustrative examples of past games, the model produces calibrated win probabilities rather than point predictions. This design allows the forecasting system to adapt dynamically to rapidly evolving pre-game conditions while remaining compatible with downstream decision-making tasks, such as trading in binary prediction markets. More broadly, our framework demonstrates how LLMs and in-context learning can be integrated into sports analytics pipelines, offering a complementary alternative to purely numeric approaches in highly stochastic environments like professional basketball.

Methods

Problem Description: LLM-based Forecasting and Trading Agents

We study the problem of probabilistic forecasting and decision-making for the professional basketball games under heterogeneous information and time constraints. Our setting combines real-time game outcome prediction with the downstream actions in binary prediction markets, such as Kalshi.

2.1 Modeling the Game Outcomes

In every NBA game, there is always a winning team and a losing team. No games end in a tie, meaning that a given team for a given game will always be limited to just one of two results: a win or a loss. In our case, the games will always be in the perspective of the home team.

Let $j \in \{1, \dots, N\}$ index NBA games.

Each game resolves to a binary outcome

$$o_j \in \{0,1\},$$



where $o_j = 1$ denotes a win by the home team and $o_j = 0$ otherwise.

2.2 Information Sets, Probabilistic Forecasting and Dynamism

Unlike classic pattern recognition tasks, a key challenge of event forecasting is its dynamism – that is, both available information for forecasting and the predicted probabilities based on the information evolves over time (before the event's resolution). Hence the time stamp of the forecasting matters a lot. At any given moment before the start of game j , the forecaster observes and information set I_j .

Given I_j , the forecaster outputs a predicted probability:

$$\rho_j \in [0,1]$$

It is interpreted as the probability that the home team wins game j at that given moment.

We use probabilistic forecasting rather than just predicting the results since probabilities are more informative and directly usable in downstream decision-making. Forecasting quality is evaluated using scoring rules such as the Brier Scores.

Dynamism.

The information is heterogeneous and time-varying, consisting of: (i) Historical Statistics; (ii) Official injury reports and lineup announcement; (iii) news articles and social media posts.

2.3 Prediction Markets and Contracts

Prediction markets are markets that allow people to trade contracts, where the value of these contracts depend on the outcome of a future event. The idea is that the trading price reflects what the market collectively believes about the likelihood of that outcome. For example, the more likely that the market believes that an event will happen, the more expensive the Yes contract for that event will become, and vice versa.

Each game j is associated with a binary prediction market.

- A Yes contract pays \$1 if $o_j = 1$ and \$0 otherwise, and is traded at price $q_j \in [0, 1]$.
- A No contract pays \$1 if $o_j = 0$ and costs $1 - q_j$.

These prices are often interpreted as the market-implied probabilities.

2.4 Sporting Betting and the Kelly Model

To formalize the betting decision, we use a fractional Kelly criterion.

Given a predicted win probability p_j and contract price q_j , the Kelly-optimal fraction of capital allocated to the favorable side is:

$$f_j \frac{(1 - q_j)p_j - q_j(1 - p_j)}{1 - q_j}$$

When betting on the Yes contract, and analogously for No. In practice, we use a fractional Kelly strategy,

$$f_j = \alpha \max(0, f_j^{Kelly})$$



where $\alpha \in [0, 1]$ controls risk aversion.

3 The Design of an LLM-based Sport Betting Agent

We propose an end-to-end framework that integrates probabilistic forecasting with market-based decision-making for NBA games under real-time constraints. The approach consists of several steps.

3.1 Phase 1: Retrieval of Event-relevant Data Sources via a Searcher Agent

We designed a unified probabilistic forecasting framework on large language models, consisting of two core components: *searchers* and *predictors*. The searchers are responsible for collecting the relevant external information, while the predictors synthesize this information to generate probability forecasts for future NBA games outcomes.

For each NBA game j , we retrieve an associated binary prediction market from NBA website and Kalshi. NBA website provides the schedule of the incoming games, and Kalshi provides a *Yes* contract price q_j and a *No* contract price $1 - q_j$.

We restrict the sample to markets that are still open, ensuring that all decisions are made before the game outcome is realized.

Searchers

On the search side, we design a set of specialized search agents which their roles are stated by their prompt. They are each responsible for a distinct dimension of NBA game outcomes, and this design enforces a clear separation of informational roles by decomposing the search process into multiple agents instead of aggregating all external data into a single unstructured input. Each agent is dedicated to a specific factor that is known to influence basketball performance. We instruct each agent to collect reliable, up-to-date information relevant to its assigned dimension. The following six search agents(searchers) are used:

- **Injury Searcher:** focuses on collecting information on player injuries across all teams, including individual injury reports and expected absences or playing restrictions
- **Star Injury Searcher:** specializes in tracking player injuries with particular emphasis on each team's star player, closely monitoring injury reports, expected absences, and restrictions that may significantly affect team performance
- **Extended Injury Searcher:** provides a comprehensive injury overview for each NBA team by analyzing official injury reports, latest updates, return timelines, and minutes restrictions, while explicitly evaluating how star player injuries influence team performance and win probability
- **Home Advantage Searcher:** analyzes home-court advantage by examining the home team's performance, the away team's road performance, and historical home-court advantage statistics
- **Rest Searcher:** evaluates scheduling-related factors by tracking days of rest and travel distance for each team to assess fatigue and recovery effects
- **Team Momentum Searcher:** assesses team momentum by monitoring winning and losing streaks as well as current league rankings

Each searcher independently queries the web using a role-specific prompt and retrieves 5 sources. The union of these sources is then passed to the prediction stage.

3.2 Phase 2: Probabilistic Forecasting with LLMs via a Predictor Agent



On the prediction side, we use multiple predictors, each representing a different forecasting perspective. This ensemble design is motivated by the idea that forecasting benefits from combining heterogeneous beliefs rather than relying on a single persona. We employ six predictors:

- **Analyst Predictor:** emphasizes quantitative evidence such as recent performance trends and historical statistics, and produces more conservative predictions
- **Fan Predictor:** is confident of the team, and captures team chemistry and intuitions
- **Sportsbook Trader Predictor:** mimics a market-orientated perspective, accounting for implied odds and risk management considerations
- **Kalshi Trader Predictor:** mimics a market-orientated perspective, but using specifically Kalshi to match public sentiment and beat the market with sharper predictions
- **Home Team Coach Predictor:** views the matchup with a basketball-oriented mind through the home team's strategy and personnel, weighing factors like player matchups, team morale, and on-court chemistry with a natural bias for their own team
- **Away Team Coach Predictor:** views the matchup with a basketball-oriented mind through the away (road) team's strategy and personnel, weighing factors like player matchups, team morale, and on-court chemistry with a natural bias for their own team

Each predictor receives the same aggregated set of sources but is guided by a role-specific prompt.

Probability Aggregation

Let s denote the Brier Score (for the definition of the Brier Score, see Section 4.1) of by predictor $k \in \{1, \dots, K\}$. For each Brier score s , we convert the score into $1 - s$, because a lower Brier Score is better. This makes the lower values correspond to better performance and a higher weight.

This is the inverse sigmoid function that we will be using:

$$\sigma^{-1}(x) = \ln\left(\frac{x}{1-x}\right)$$

We plug this value $1 - s$ into the inverse sigmoid (logit) function to find the raw weight of each predictor.

$$w_k = \sigma^{-1}(1 - s) = \ln\left(\frac{1 - s}{1 - (1 - s)}\right) = \ln\left(\frac{1 - s}{s}\right)$$

We then normalize the weights by taking a sum of the raw weights of our K predictors and dividing each raw weight by the sum:

$$\text{Normalized Weight} = \frac{w_k}{\sum_{l=1}^K w_l}$$

Then the aggregated the predicted probability for game j is computed as:

$$p_j^{agg} = \sum_{k=1}^K w_k p_{j,k}$$

3.3 Phase 3: Betting Optimization and Execution via a Trading Agent



To translate probabilistic forecasts into trading decision, the understanding employs a decision rule based on expected (EV) with fractional Kelly betting. This framework shows how rational agents should act in prediction markets when probabilities are estimated with uncertainty.

The Fractional Kelly Betting

After selecting the trade direction, the position size is determined using the Kelly Criterion (Wysocki 2025) which specifies the optimal fraction of capital to bet in order to maximize long-run benefit. For a contract purchased at price c with win probability p_{adj} , the Kelly fraction f^* is given by:

$$f^* = \frac{(1 - c)p_{adj} - (1 - p_{adj})c}{c}$$

In practice, full Kelly betting assumes accurate probability estimates and can therefore lead to excessive volatility when probabilities are not specified. To reduce the risk, the strategy employs *fractional Kelly betting*, scaling the optimal fraction by a constant $\alpha \in (0, 1)$: i.e., $f = \alpha f^*$.

In our study, we set $\alpha = 0.20$, meaning that only 20% of the full Kelly criterion is used. This conservative adjustment acknowledges in p_{adj} and reduces the impact of probability estimation errors on position sizing.

Additionally, a hard cap is imposed on the amount of betting per game. The final stake size is therefore computed as:

$$Stake = \min(Bankroll \times f, MaxBet)$$

This cap prevents the strategy from allocating excessive capital to a single trade, even when the Kelly criterion suggests a large position. Such position limits are standard in real-world trading markets and serve as an additional layer for risk management. Algorithm 1 presents the full algorithmic procedure as a concise, rule-based framework.

Algorithm 1 Trading Algorithm with EV Threshold and Fractional Kelly

1. Inputs:

- Adjusted probability (p_{adj})
- Market YES price ($mktYES$)
- Market NO price ($mktNO$)
- Current Bankroll (B)
- EV threshold (τ)
- Fractional Kelly parameter (α)
- Maximum stake per game (C)

2. Step 1: Compute expected values

- $EV_{YES} = p_{adj} - mktYES$
- $EV_{NO} = (1 - p_{adj}) - mktNO$

3. Step 2: Apply EV threshold

- If $\max(EV_{YES}, EV_{NO}) < \tau$, set decision = HOLD and stop.

4. Step 3: Select trade side

- If $EV_{YES} \geq EV_{NO}$:
– side=YES, $p_{win} = p_{adj}$, $c = mktYES$
- Else:
– side = NO, $p_{win} = 1 - p_{adj}$, $c = mktNO$



5. Output:

- Trade decision (YES / NO / HOLD)
 - Number of contracts
 - Execution Price
-

Implications of Using Adjusted Probabilities

The use of p_{adj} highlights that trading decisions are made under uncertainty rather than perfect foresight. The combined use of adjusted probabilities expected value thresholds, fractional Kelly sizing, and position caps leads to three key outcomes. First, many markets are intentionally skipped,

reflecting disciplined selectivity. Second, higher EV thresholds results in fewer but more profitable trades which indicates that filtering weak signals is more important than trade frequency. Lastly, the results, demonstrate that the Kelly criterion is effective when it is used with conservative adjustments that reduce errors in probability estimation.

Overall, this framework shows that profitability in prediction market depends not only on estimating probabilities, but on recognizing and managing uncertainty in those predictions. These considerations are incorporated into rule-based trading algorithm that uses adjusted probability estimates, expected value filtering, and fractional Kelly sizing to determine whether and how to trade.

Results and Discussion

We evaluate the proposed system from both a predictive and decision-making perspectives. Our primary focus is on the probabilistic calibration and downstream economic performance in the prediction markets.

4.1 Evaluation Metrics.

4.1.1 Brier Score

Since our model outputs probabilistic forecasts, we evaluate the predictive quality using the Brier Score. For a set of N games, the Brier Score is defined as:

$$BS = \frac{1}{N} \sum_{j=1}^N (p_j - o_j)^2$$

where $p_j \in [0, 1]$ is the predicted probability that the home team wins game j , and $o_j \in \{0, 1\}$ is the realized outcome of game j .

Proposition 1

Suppose p, q are two different probability forecast for an event E , then the Brier score for $\lambda p + (1 - \lambda)q$ is a quadratic function in $\lambda \in [0, 1]$.

Proof. Suppose $p, q \in [0, 1]$ are two distinct probabilistic forecasts for a binary event E , and let:

$$\hat{p}(\lambda) = \lambda p + (1 - \lambda)q, \quad \lambda \in [0, 1]$$



Let the $p^* \in [0, 1]$ denote the true probability of E, and $O \in \{0, 1\}$ denote the realized outcome of the event, with:

$$P(O = 1) = p^*, \quad P(O = 0) = 1 - p^*$$

The Brier score for a forecast r is:

$$\begin{aligned} BS(\lambda) &= E[(\hat{p}(\lambda) - O)^2] \\ &= E[\hat{p}(\lambda)^2 - 2\hat{p}(\lambda)O + O^2] \\ &= \hat{p}(\lambda)^2 - 2\hat{p}(\lambda)E[O] + E[O^2]. \end{aligned}$$

Since $O \in \{0, 1\}$, we have $O^2 = O$, and therefore,

$$E[O] = E[O^2] = p^*$$

which gives:

$$BS(\lambda) = \hat{p}(\lambda)^2 - 2p^*\hat{p}(\lambda) + p^*$$

Since

$$\hat{p}(\lambda) = q + \lambda(p - q)$$

is a linear function of λ . Hence the $\hat{p}(\lambda)^2$ is a quadratic function of λ , therefore, the brier score $BS(\lambda)$ is a quadratic function of λ as well.

More explicitly, letting $\Delta = p - q$, we obtain:

$$BS(\lambda) = \Delta^2 \lambda^2 + 2\Delta(q - p^*)\lambda + (q - p^*)^2 + p^*(1 - p^*)$$

Proposition 2

The function $BS(\lambda)$ is convex in λ and is monotone on $[0, 1]$ if and only if $p \notin [\min(p, q), \max(p, q)]$.

Proof. From the quadratic expansion in the previous claim, the coefficient of λ^2 is $(p - q)^2 \geq 0$, so $(BS)(\lambda)$ is convex.

Take the derivative over λ :

$$BS'(\lambda) = 2(p - q)\hat{p}(\lambda) - p^*$$

Setting the derivative to zero gives the minimizer:

$$\lambda^* = \frac{p^* - q}{p - q}$$

if $\lambda^* \in (0, 1)$, then the $BS(\lambda)$ decreases for $\lambda < \lambda^*$ and increases for $\lambda > \lambda^*$, and hence not monotone on $[0, 1]$. This occurs if and only if $p^* \in (\min(p, q), \max(p, q))$



If instead $\lambda^* \leq 0$ or $\lambda^* \geq 1$, the minimum is attained at an endpoint, and the function is monotone on $[0, 1]$.

The condition $p^* \notin [\min(p, q), \max(p, q)]$ implies either p, q are both smaller than p^* , or are both larger – that is, they make the same forecasting mistake of being overly optimistic or overly pessimistic. Claim 2 formally show that in such situation, the mixed Brier score is monotone, hence the best choice is to choose $\lambda = 0$ or 1 , i.e., to not mix. On the other hand, if $p^* \in [\min(p, q), \max(p, q)]$, this implies one of p, q overestimates p^* whereas the other underestimates p^* . In this situation, mixed forecaster can do better. This echoes the fundamental insight of boosting (Schapire 1990) that boosting is helpful when different weak learner/forecasters have strengths over different subsets of data points or tasks.

4.1.2 Expected Calibration Error

While proper scoring rules such as the Brier Score evaluate the overall accuracy of probabilistic forecasts, they do not directly assess whether the predictions are well calibrated. Calibration measures whether events predicted to occur with probability p indeed occur approximately p fraction of the time.

We evaluate calibration using the Expected Calibration Error (ECE). The ECE quantifies the discrepancy between predicted probabilities and empirical outcome frequencies by partitioning predictions into bins.

Let $\{(p_j, o_j)\}_{j=1}^N$ denote the predicted probabilities and realized outcomes for N NBA games, where $p_j \in [0, 1]$ is the predicted probability that home team wins game j , and $o_j \in \{0, 1\}$ is the realized outcomes.

We divide the unit interval $[0, 1]$ into M disjoint bins $\{B_m\}_{m=1}^M$. For each bin B_m , define:

- $|B_m|$: the number of games whose predicted probabilities fall into bin B_m ,
- $\text{conf}(B_m) = \frac{1}{|B_m|} \sum_{j \in B_m} p_j$: the average predicted probability in the bin,
- $\text{acc}(B_m) = \frac{1}{|B_m|} \sum_{j \in B_m} o_j$: the empirical frequency of home-team wins in the bin.

The Expected Calibration Error is then defined as:

$$ECE = \sum_{m=1}^M \frac{|B_m|}{N} |\text{acc}(B_m) - \text{conf}(B_m)|$$

Intuitively, ECE measures the weighted average absolute deviation between predicted probabilities and observed outcome frequencies across bins. A perfectly calibrated forecasting system attains $ECE = 0$, while larger values indicate increasing miscalibration.

4.1.3 Simulated Market Returns

To evaluate the system, we simulate the market settlement. Given the realized outcomes o_j , the profit-and-loss (PnL) for each bet is computed as the contract payoff minus its cost.

4.2 Evaluation of the Forecasting Agent

Experimental Setup



To evaluate the performance of the forecasting agents, a total of 39 NBA games across 5 days were evaluated. Three initial predictor agents (Analyst, Fan, Sportsbook Trader) were used for the first 29 games across 4 days, and for the final day with 10 games, an additional three predictors (Kalshi Trader, Home Team Coach, Away Team Coach) were added on top of the existing three that we originally had. Games from December 29th, 2025 to January 2nd, 2026 were used.

To set up the testing, a prompt was fed into the forecasting agent, and this prompt asked the agent for a probability between 0 and 1 for the home team to win for this specific NBA game. The two teams involved in the game, the home team, the date, and the location of the game were involved in this prompt, making it detailed and clear in what we were asking for. The close times for the LLM to obtain sources and conduct research were set to prior to the start of the given game.

After each run, the predicted win probabilities for each of the different predictor agents involved in forecasting that NBA game were recorded on a spreadsheet. The descriptions of each of these agents and their specific roles can be found in Section 3.2. In addition, to compare our predictor agents' results with the actual market and what the general population thought, we also recorded the home team win probabilities for all of the games from Kalshi, an online prediction market. These win probabilities were retrieved from Kalshi at the point 24 hours before the start of each NBA game. This was done to ensure that a stable and accurate prediction of the prediction market was obtained, as fluctuations in the win probabilities would be too volatile close to the start of the game or especially during the game itself. It also wouldn't be a fair prediction, as these fluctuations would likely be influenced by information that wouldn't have been available to our forecasting agent at the close time that we set.

Finally, in addition to recording the win probabilities for each of the predictor agents and the Kalshi market, we also recorded the binary realized outcome for the home team after the games had taken place. A win for the home team results in 1, and a loss for the home team results in 0.

Experimental Results

Table 1 reports the predicted home team win probabilities produced by different forecasting personas, or agents, together with the realized game outcomes and the corresponding market prices. This is data from NBA games on January 2nd, 2026, and these were the 10 games in which all 6 predictor agents were used.

For each NBA game, we collect the home-team winning probabilities from multiple predictors. These forecasts are compared with the realized game outcome, where a home-team winning coded as 1. We also included the Kalshi market prices as a market-implied benchmark probability.



Table 1: Predicted Home Win Probabilities and Game Outcomes

Date	Game	Home Team	Analyst Prob	Fan Prob	Sportsbook Trader Prob	Kalshi Trader Prob	Home Coach Prob	Away Coach Prob	Result (Win=1)	Market Prob (Kalshi)
Jan 2, 2026	1: IND vs SAS	IND	0.30	0.33	0.33	0.33	0.40	0.34	0	0.33
Jan 2, 2026	2: WAS vs BKN	WAS	0.64	0.70	0.62	0.60	0.64	0.59	1	0.59
Jan 2, 2026	3: CLE vs DEN	CLE	0.74	0.82	0.78	0.74	0.74	0.75	1	0.86
Jan 2, 2026	4: NYK vs ATL	NYK	0.71	0.76	0.66	0.67	0.71	0.58	0	0.72
Jan 2, 2026	5: CHI vs ORL	CHI	0.37	0.43	0.35	0.36	0.42	0.35	1	0.35
Jan 2, 2026	6: MIL vs CHA	MIL	0.73	0.75	0.73	0.74	0.74	0.68	1	0.66
Jan 2, 2026	7: NOP vs POR	NOP	0.66	0.77	0.68	0.65	0.68	0.66	0	0.48
Jan 2, 2026	8: PHX vs SAC	PHX	0.76	0.81	0.77	0.81	0.76	0.69	1	0.84
Jan 2, 2026	9: GSW vs OKC	GSW	0.22	0.21	0.18	0.22	0.24	0.24	0	0.16
Jan 2, 2026	10:LAL vs MEM	LAL	0.64	0.69	0.64	0.65	0.65	0.58	1	0.60

Table 2 below shows the Brier scores for each of the 6 different personas, or predictor agents, along with the Brier score of the Kalshi prediction market. As mentioned in the experimental setup, all 6 agents were only tested for 10 games, while the first 3 were tested for all 39 games that were evaluated as the sample size.

Table 2: Brier Score for Each Predictor Agent

	Analyst	Fan	Sportsbook Trader	Kalshi Trader	Home Coach	Away Coach	Market (Kalshi)
Brier Score (10 games)	0.1932	0.1966	0.1910	0.1892	0.1965	0.1973	0.1795
Brier Score (39 games)	0.1982	0.2031	0.1990	N/A	N/A	N/A	0.1876

Key Takeaways

There are multiple key takeaways that can be formed from the evaluation and results of the forecasting agent. First, Table 1 shows substantial heterogeneity across forecasting personas. This means that each persona, as it should, gives its own unique opinion on the game at hand in according to their personal role and what they look at and are more knowledgeable in. For example, it can be seen that fans and coaches tend to produce more extreme probabilities, while the analyst and trader predictors are generally more conservative. That is why a combination of different predictors is often used, as it can be seen as the most beneficial and accurate, as it incorporates all different unique views, taking each agent's strengths to make the best possible prediction. And even in situations where a combination of different agents don't result directly in a lower Brier score for a given sample size of games, this method can still be worth integrating. Oftentimes, especially in smaller sample sizes, results may be unstable as one or two games can largely impact the final score as a whole. One decently wrong prediction or upset in an NBA game could sway a Brier score up or down within a small set of NBA games. This leads to certain agents showing to be more accurate in some sets of



games, while others showing to be more accurate in another set of games, which is why a blend can still be helpful in the grand scheme and looking towards a more consistent forecasting agent.

Next, as seen in Table 2, it is an extremely difficult task to beat the market in accuracy, especially over a big range of games. A prediction market like Kalshi is built off of real people betting their money as they see events and information come up in real time. It is also therefore an aggregation of a wide range of opinions in the population, and this inevitably makes a prediction market like Kalshi immensely consistent and a naturally excellent forecaster. Beating the market consistently would mean that money could be earned at a high rate in the real world.

Finally, one trend that was noticed for these NBA games was that the predictor agents and the LLM as a whole tend to not be as confident in their predictions for lopsided games. When one team is clearly better than another team, the prediction market and the general population tend to favor the better team heavily, regardless of home/away games, injuries, rest days, travel distance, or other factors. However, the predictor agents seem to overestimate the impact of these secondary factors, oftentimes giving a bad team a higher chance of winning than what they are capable of. And while this strategy can prove successful sometimes through upsets, these upsets are unexpected and are upsets for a reason. They are rare and one underdog win here or there doesn't make up for the constant, consistent predictions that the prediction market makes game by game. This phenomenon also proves to be truer as the sample size gets larger, as outliers are increasingly overshadowed by the majority, making the more consistent and bolder predictor more accurate regarding these lopsided games.

4.3 Evaluation of the Trading Agent

Experimental Setup To evaluate the performance of the trading agent, a series of controlled simulation experiments were conducted using real-world NBA prediction market prices. Market prices for YES and NO contracts were retrieved from an online prediction market platform, Kalshi, where each contract pays \$1 if the corresponding event occurs and \$0 otherwise. These prices reflect the aggregated beliefs of market participants and serve as a benchmark for evaluating the agent's decisions.

The trading agent operates in two stages. First, it produces a forecasted probability for each game outcome. These probabilities are treated as *adjusted probabilities*, acknowledging uncertainty and potential estimation error rather than assuming perfect foresight. Second, the agent compares these adjusted probabilities against market prices using an expected value (EV) framework.

$$EV_{YES} = p_{adj} - yes_price, \quad EV_{NO} = (1 - p_{adj}) - no_price.$$

Trades are executed only when the estimated edge exceeds a predefined EV threshold τ , such that

$$\max(EV_{YES}, EV_{NO}) \geq \tau$$

When this condition is satisfied, the agent selects the contract (YES or NO) with the higher expected value; otherwise, it chooses to HOLD and does not place a trade. Position sizes are then determined using fractional Kelly betting with a fixed cap on the maximum stake per game.

The EV threshold is introduced to control the trade-off between selectivity and aggressiveness, limiting trades based on marginal edges that may arise from estimation noise rather than genuine market mispricing. To assess the sensitivity of the agent to this decision criterion, experiments are conducted under multiple threshold settings.



All experiments are performed in a backtesting environment that simulates contract settlement using realized game outcomes. The agent begins with a fixed initial bankroll and trades sequentially across games, allowing profits and losses to accumulate over time.

Experimental Results

To assess the sensitivity of the trading agent to its decision criteria, multiple experiments were conducted using different EV thresholds. The EV threshold determines how selective the agent is when deciding whether to place a trade. Results in Table 3 reveal a clear trade-off between trade frequency and profitability. When a low EV threshold of 0.5% is used, the agent places a large number of trades but overall gets a negative return. This suggests that small apparent edges are often dominated by probability estimation error and market noise. Increasing the threshold to 1% yields modest positive returns, while a higher threshold of 2% results in fewer trades but substantially higher overall profitability.

Table 5: Performance of the Trading Agent under different EV Thresholds

EV Threshold	Trades Placed	Total PnL(\$)	Final Bankroll(\$)
0.5%	19/29	-166.36	2733.64
1.0%	17/29	+205.39	3105.39
2.0%	14/29	+408.22	3308.22

These findings indicate that filtering weak signals is more important than increasing trading frequency. By restricting trades to situations where the model's confidence exceeds market prices, the agent is better to use genuine mis-pricings rather than fluctuations caused by noises.

Key Takeaways

Several key lessons emerge from the evaluation of the trading agent. First, probability accuracy alone is insufficiently for profitable trading. Even reasonably calibrated probability estimates can lead to losses if trades happen too aggressively or without filtering. Second, the Kelly criterion must be applied conservatively in practical settings. Fractional Kelly sizing and position caps are essential to mitigate risk when probability estimates are uncertain. Third, disciplined selectivity -choosing not to trade in many markets- is a critical component of long-term profitability.

Conclusion

This paper presents a unified framework that integrates large language models with prediction-market-based decision making for probabilistic forecasting of NBA game outcomes. By leveraging timely unstructured textual information and aggregating heterogeneous LLM-based predictors, our approach moves beyond traditional data-driven models and produces calibrated win probabilities that are actionable in binary markets. The empirical results highlight the value of the probabilistic aggregation and disciplined betting strategies, such as fractional Kelly, in linking forecast quality to economic performance. Overall, our findings suggest that LLMs offer a promising direction for sports analytics in uncertain environments.

For the search agent, several extensions can be considered for future work. First, during the source aggregation process, the number of sources retrieved by each search agent can be varied. This would allow us to examine whether adjusting the number of sources from each agent leads to improved performance and to identify the best set of numbers. Through this analysis, we can also assess



whether the number of sources for each agent meaningfully reflects the importance of each factor represented by the agents. Second, we can investigate the relationship between the performance and the number of search agents used. In this study, we evaluated cases in which one or two agents were employed. Extending this to three or more agents would allow us to determine whether increasing the number of agents consistently improves performance, or whether there exists a saturation point which additional agents provide limited benefit. Finally, we can analyze whether the set of agents that performed best individually also forms the optimal joint set. For example, although the 'Extended Injury' agent had a lower Brier score than the 'Star Injury' agent, the set of 'Extended Injury' agent and 'Team Momentum' agent, which we used in this study, may have a higher Brier score than the set of 'Star Injury' agent and 'Team Momentum' agent. Since the complementary relationship between agents may affect the result of the sets of search agents, to systematically evaluate such interactions. In the future work, we can explore all possible combinations of agents and assess their joint effectiveness.

In terms of the forecasting agent, future work could integrate going the extra mile to add a larger variety of different personas, truly testing tens or hundreds of unique and creative roles to see which ones can breed the most accurate predictions and even have a chance at beating the market. In addition, future work could involve a bigger sample size, going from a couple of days' worth of games to months or even throughout an entire season to improve the validity of results. A larger sample size would allow clearer information on which agents are truly consistent and reliable over lots of data, and which agents show to have promising signs over smaller, favorable sets of games but fail to be accurate throughout the whole. Finally, future work could also explore a system of automated persona design, where techniques such as reinforcement learning would modify and create personas in groups so that the fit between these personas, when weighted and aggregated, would allow for the best possible prediction and lowest Brier score. These would automate and modify agent traits organically that also fit together well, in that each persona would be specialized and knowledgeable in different aspects of basketball and the NBA, so that the cumulative result after intentional weighting would breed favorable and possibly unprecedented results.

With respect to the trading agent, an important direction for future work would be the development of a language-model based trading agent that directly outputs both probability forecasts and stake recommendations given observed market prices and a fixed budget. This approach would integrate prediction and decision-making into a single agent. This will enable joint reasoning over uncertainty, expected value, and capital allocation. However, such a trading agent would also introduce additional risks, as protective measures would be required to prevent overconfidence and excessive risk-taking when probability estimates are not perfect.

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References

- Brown, Tom et al. (2020). "Language models are few-shot learners". In: *Advances in neural information processing systems* 33, pp. 1877–1901.
- Gumm, Jordan, Andrew Barrett, and Gongzhu Hu (2015). "A machine learning strategy for predicting march madness winners". In: IEEE, pp. 1–6. ISBN: 1-4799-8676-3.
- Horvat, Tomislav et al. (2023). "A data-driven machine learning algorithm for predicting the outcomes of NBA games". In: *Symmetry* 15.4. Publisher: MDPI, p. 798. ISSN: 2073-8994.



Kim, Jun Woo, Mar Magnusen, and Seunghoon Jeong (2023). "March Madness prediction: Different machine learning approaches with non-box score statistics". In: *Managerial and Decision Economics* 44.4. Publisher: Wiley Online Library, pp. 2223–2236. ISSN: 0143-6570.

Liu, Yiheng et al. (2023). "Summary of chatgpt-related research and perspective towards the future of large language models". In: *Meta-radiology* 1.2. Publisher: Elsevier, p. 100017. ISSN: 2950-1628.

Ozkan, Ilker Ali (2020). "A novel basketball result prediction model using a concurrent neuro-fuzzy system". In: *Applied Artificial Intelligence* 34.13. Publisher: Taylor & Francis, pp. 1038–1054. ISSN: 0883-9514.

Pathak, Neeraj and Hardik Wadhwa (2016). "Applications of modern classification techniques to predict the outcome of ODI cricket". In: *Procedia Computer Science* 87. Publisher: Elsevier, pp. 55–60. ISSN: 1877-0509.

Schapire, Robert E (1990). "The strength of weak learnability". In: *Machine learning* 5.2. Publisher: Springer, pp. 197–227. ISSN: 0885-6125.

Tax, Niek and Yme Joustra (2015). "Predicting the Dutch football competition using public data: A machine learning approach". In: *Transactions on knowledge and data engineering* 10.10, pp. 1–13.

Thabtah, Fadi, Li Zhang, and Neda Abdelhamid (2019). "NBA game result prediction using feature analysis and machine learning". In: *Annals of Data Science* 6.1. Publisher: Springer, pp. 103–116. ISSN: 2198-5804.

Wei, Jason et al. (2022). "Emergent abilities of large language models". In: arXiv preprint arXiv:2206.07682. Wysocki, Maciej (2025). "Sizing the Risk: Kelly, VIX, and Hybrid Approaches in Put-Writing on Index Options". In: arXiv preprint arXiv:2508.16598.

Zhao, Kai, Chunjie Du, and Guangxin Tan (2023). "Enhancing basketball game outcome prediction through fused graph convolutional networks and random forest algorithm". In: *Entropy* 25.5. Publisher: MDPI, p. 765. ISSN: 1099-4300.

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The Drowning Child vs. the Law: Bridging Legal Positivism and Moral Duty

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Introduction

Imagine receiving a distress call that 400 people—60 among them children—are drowning. Technically, these drowning passengers are in Malta's search and rescue zone, but Italy's rescue team is much closer. This faster response time may determine their survival. What should be done?

The Italian authorities ended up sending a rescue team, but not before turning a blind eye to 4 hours and 41 minutes of pleading calls. The Italian government insisted it had no legal obligation. 60 children and a total of 268 people drowned. 9 years of legal battle later, the UN Human Rights Committee found that Italy failed to protect their right to life (OHCHR, 2021). A year later, Italy's domestic court also found defendants guilty but not punishable because the statute of limitations expired.

One could argue that no legal wrong was done from a positivist view—a framework that focuses on law that has been formally posited and practiced. This paper will explore arguments similar to the UN Human Rights Committee's claim that Italy should have done something. Not only because it is required by international law, but also because it is the moral thing to do. From this real-life example of Peter Singer's well-known drowning child analogy, this paper will argue that compliance in international human rights law can increase by incorporating natural law, a moral obligation in agreement with nature applicable everywhere.

Not to mention, this paper will further explore a research puzzle that stems from a tragedy like the above shipwreck. If natural law is so self evident and appealing everywhere, why hasn't it already been universally accepted and posited as the formal law? One may argue that there is a lag between natural law being recognized as morally universal and it becoming codified into formal law. Especially in international law, the large number of stakeholders needed to ratify international law makes this lag more pronounced and has led to sweeping efforts in codifying natural law into international law. Under this assumption, what can be done to have better compliance in international law that is universally appealing but still suffers from low compliance?

This paper will highlight the Nuremberg trials as an example where natural law was not yet fully codified. Egregious violations such as genocide, crimes against humanity, and aggressive war have led to closing this gap faster. This paper will then cover the Universal Declaration of Human Rights (UDHR) and International Covenant on Civil and Political Rights (ICCPR) as examples of a pre-emptive effort to codify universal moral principles before more violations of human rights occur. From the above case studies, the paper will grapple with ways to increase compliance in international human rights law.

Literature Review

This literature review looks closely at the foundations of applying natural law to international human rights law. It will define the legal frameworks underlying this analysis, including natural law, positivist law, and the theory of compliance. Literature on natural law will help define the main idea we seek to discuss in the paper. It will also briefly survey positivist frameworks to offer the opposing viewpoint seen in the Italian shipwreck case. Then, it will look into compliance theory, famously laid out by Kal Raustiala, to look at how to improve compliance in international law. The survey of natural law and compliance theory is also aimed



at helping future efforts of a quantitative analysis that categorizes international law into those that incorporate natural law or do not, and compares their corresponding compliance rates.

Natural law is defined as the right reason in agreement with nature, applicable everywhere, fixed, and perpetual (West, 1981)(Alonso, 2011). Natural law has a normative appeal of how law should be rather than how it already is. Especially for humanitarian disasters like the shipwreck case, natural law lends a more persuasive voice on what should be done rather than what is strictly legal or not. Cicero, a Roman statesman and legal theorist, argues that this universal moral code exists beyond state laws.

Legal positivism, however, is a view that law derives solely from social facts adapted through formal law, rather than inherent moral value (Stanford Encyclopedia of Philosophy, 2025). Some scholars such as HLA Hart even go further in a “separation thesis” that there is no conceptual connection between law and morality. Law can be legally valid even if morally deplorable (Hart, 1961).

John Austin, who is more moderate in his theoretical framing, argues that law must have state consent, territorial sovereignty, command of the sovereign, and a threat of sanction. While it is easy to think of natural law and positivist views to be in direct contrast as shown in the above shipwreck case, the reality is that there is a lag in between recognition of a natural law versus ratification into positivist law. Prosper Weil is the biggest proponent of positivism that acknowledges this lag in how law should be (*lex ferenda*) rather than how it already is (*lex lata*). Weil not only argues there is a lag between the two but argues that they should remain rigidly distinct. Weil’s argument, however, doesn’t answer the question of natural law, as defined. If natural law is so natural and universal, why isn’t it already universally accepted and ratified as international law? International institutions are relatively new, and it therefore takes time for natural law to be ratified. Oscar Schachter describes this lag as a “twilight existence” of norms that are not illegal to ignore but carry heavy political and moral costs (Schachter, 1977).

Kal Raustiala’s theory of compliance shifts the question from whether a country has legal obligations to whether states comply with that obligation. Raustiala distinguishes between compliance—states conforming to a rule—versus effectiveness—the rule achieving its intended policy goal (Raustiala, 2000). In other words, even though positivist laws may show high compliance rates, if the regulations fail to address the underlying humanitarian issue as seen in the shipwreck, the law is ineffective.

Compliance theory helps address the research puzzle of how to improve compliance in international law. Raustiala argues that behavioral conformity is most robust when a state’s institutional arrangements align with its internal normative commitments (Raustiala, 2000). Harold Koh describes this phenomenon as “internalization” of international norms into a state’s domestic legal system (Koh, 1997). Scholars contend that the appeal of natural law principles will exert a comparable intrinsic moral pull (West, 1981). This paper will explore whether framing human rights as universal moral truths, instead of mere social institutions will enhance the legitimacy of natural law and its compliance.

Gap in Literature

This literature review will identify three well-developed areas of research (1) an ongoing jurisprudential debate between natural law and legal positivism; (2) international relations theory on the mechanisms of state compliance; and (3) a thorough historical and legal analysis of the philosophical roots of important human rights instruments.

The gap in literature lies at the intersection of these fields. Although the philosophical argument that natural law offers a stronger basis for moral obligation is commonly asserted, there is a significant lack of research on the process by which a commitment to natural law principles results in greater compliance with positivist international human rights law.



This analysis is positioned to begin bridging the gap between jurisprudence and compliance studies. By utilizing Kal Raustiala's normative alignment and Harold Koh's theory of internalization, this paper argues that natural law is not only philosophical ideal but also a powerful mechanism for internalization. While Raustiala's concept of normative alignment explains compliance as a function of how closely international obligations correspond with a state's internal values and interests, Koh's theory of internalization explains how the international norms become ingrained in domestic legal systems.

When human rights laws are presented as reflections of innate moral truths rather than as externally imposed requirements, they attain the normative resonance necessary for voluntary and long-lasting compliance. This study tests this theory by employing historical case studies of the Nuremberg Trials, the UDHR, the Genocide Convention, and the ICCPR, offering proof of this mechanism in action during the most crucial early stages of the international human rights regime. Through this lens, moral norms can be both a stage of legal development and a powerful force that, once codified, guarantees a more robust and efficient international order.

Hypotheses

This paper will investigate the following hypotheses to address the research question on enhancing compliance in international law.

- H0: The integration of natural law ideologies does not upsurge compliance with civil and political rights.
- H1: The inclusion of natural law concepts into human rights law could boost since states and individuals will see these rights as a moral obligation rather than a legal one.
- H2: The adoption of natural law concepts in human rights law may reduce compliance because the vagueness of these principles may lead to selective interpretation that benefits noncompliance.
- H3: Incorporating natural law principles may promote compliance with civil and political rights because various cultural norms allow states to be more adaptable.
- H4: Human rights law has already been integrated into natural law, which has had no apparent effect on states' adherence to civil and political rights.

Methodology

A well structured case-study method is ideal for this research because it clearly allows an individual to trace the changing relationship between moral principles and legal codification over time. By examining Nuremberg, the UDHR, the Genocide Convention, and the ICCPR in sequence, the analysis captures how natural law moved from moral appeal to declaratory norms, to binding legal obligations. This temporal structure makes it possible to assess whether increased legalization corresponds with improved compliance, or whether moral grounding remains the decisive factor.

Justification of Case Selection

This paper uses a method for picking cases that aim to trace the evolution of natural law principles from moral intuition to binding international legal obligation. The cases of the Nuremberg Trials, the Genocide Convention, the Universal Declaration of Human Rights (UDHR), and the International Covenant on Civil and Political Rights (ICCPR) are chosen because they represent key moments in the development of the modern international human rights system.



The Nuremberg Trials serve as a prime example of how natural law principles were explicitly invoked to bypass positivist limitations. At the time of the trials, many of the acts prosecuted were not clearly defined as crimes under existing international law. Nuremberg thus provides a crucial test case to see if moral legitimacy can lead to compliance even without prior legal codification.

The Genocide Convention is selected as it represents the quick codification of a universally recognized moral wrong into binding international law. Genocide was defined as an international crime, based on the protection of humanity itself after the moral shock of the Holocaust. This law makes it easier to examine how moral consensus speeds up the shift from natural law to positive law.

The UDHR and ICCPR are chosen as founding documents of the international human rights system. The UDHR is widely seen as the main basis of international human rights law, while the ICCPR gives binding legal power to many of its moral principles. Together, they form what the Office of the High Commissioner for Human Rights calls the “International Bill of Human Rights.” Their inclusion allows us to explore how compliance behavior is influenced by early moral codification and later treaty-based legalization.

These four cases enable comparison across different levels of legalization, enforcement, and moral grounding. This comparative structure is vital for evaluating the paper’s hypotheses about whether incorporating natural law principles improves compliance with civil and political rights.

Nuremberg Trials

The Nuremberg Trials of 1945-1946 marked a historic turning point in international law. After the defeat of Nazi Germany, the Allied powers aimed to hold high-ranking Nazi officials accountable for the atrocities committed during World War II. These crimes included mass murder, enslavement, deportation, and other inhumane acts against civilians. To prosecute these crimes, the Allied powers established an international tribunal under the London Charter of August 8, 1945, which empowered the court to try individuals, not just states, for crimes against humanity and war crimes.

The defendants presented a legal challenge to this tribunal, claiming their actions were lawful under domestic German law or justified by obedience to superior orders. Consequently, the trials became a crucial point for applying natural law principles, which state that the law must align with universal moral truths rather than just positive statutes. By doing so, Nuremberg aimed to bridge the gap between legality and morality after mass atrocity.

Natural Law and Legal Reasoning

The Nuremberg Tribunal represented a conflict between legal positivism, which holds that law is valid if passed by recognized authorities, and natural law, which asserts that laws must adhere to moral and ethical principles. Nazi supporters often used traditional positivist arguments, citing sovereignty or obedience to commands as their defenses. The Tribunal consistently rejected these claims, emphasizing that individuals have duties to humanity that go beyond national law.

Article 6(c) of the London Charter defined crimes against humanity to include “murder, extermination, enslavement, deportation, and other inhumane acts committed against any civilian population, before or during the war.” This definition highlighted the Tribunal’s reliance on moral wrongdoing rather than strict legal violations. By stressing universal norms of human dignity, the court underscored a fundamental principle of natural law: legality must be guided by ethical reasoning.

The American case of *Riggs v. Palmer* (1889) provides a historical parallel. In this case, a grandson murdered his grandfather to inherit under a will. Although no laws explicitly forbade this, the court ruled that “no one shall profit by their own wrong,” reflecting the natural law principle that morality can take precedence over the literal application of law. Similarly, Nuremberg prosecutors argued that Nazi crimes, while



sometimes permissible under domestic law or orders, violated fundamental principles of humanity and justice. Both cases show that moral accountability can be enforced even when statutory law falls short of ethical standards.

Lag of Natural Law in Practice

Despite its successes, the Nuremberg Trials showed the limitations of natural law within strict legal systems. One significant challenge was the idea of ex-post facto prosecution: defendants claimed they were being tried for actions that were not considered crimes at the time they occurred. This illustrates the delay of legislation in relation to evolving moral standards, where formal laws do not always capture emerging ethical norms.

Another issue was defining the meaning and scope of crimes. Initial prosecutions limited crimes against humanity to wartime acts (the so-called “war nexus”), leaving out many atrocities committed before 1939. Later tribunals under Control Council Law No. 10 expanded the list of inhumane acts to include torture and rape, better aligning legal definitions with universal moral principles. These cases reveal the challenges of turning natural law concepts into enforceable legal structures while maintaining legitimacy.

Tribunal’s Approach to Morality and Law

The Nuremberg Tribunal blended moral reasoning with legal obligations. Defenses based on absolute sovereignty or superior orders were consistently dismissed, emphasizing that formal obedience cannot justify moral wrongs. The prosecution argued that violations of human dignity breach duties owed to all of humanity, not just violations of domestic laws.

Scholars like Paulson note that this approach required recognizing moral grounds as part of legal validity, showing that law achieves justice only when it aligns with ethical principles. By prosecuting crimes against humanity and including them within international law, Nuremberg set a precedent for holding individuals accountable for universal moral violations.

The Nuremberg Trials had ideological and educational impacts. They established that major violations of human rights are the responsibility of individuals, not nations, and that universal ethical norms can define crimes against humanity. The trials raised awareness of legal reasoning and moral principles, educating officials and citizens on the value of justice and human dignity. Notable scholars have highlighted Nuremberg’s foundational role in modern human rights law. Hannah Arendt stated it recognized that crimes against humanity are offenses against humanity. David Luban emphasized the need for individual moral accountability beyond state consent. Antonio Cassese saw the trials as the beginning of modern international criminal law. Judith Shklar noted the transition of moral anger into enforceable legal norms. Martti Koskeniemi highlighted the inclusion of moral reasoning into legal authority. Collectively, these viewpoints confirm that Nuremberg changed international law by rejecting absolute sovereignty, establishing accountability based on universal moral principles, and institutionalizing individual responsibility.

The Nuremberg Trials also provide evidence for theories about natural law and compliance. Compliance was obtained despite the absence of prior legal codification because the crimes prosecuted were clearly morally wrong, and universal moral values provided legitimacy that positivist legality could not. Ambiguity in moral principles, such as ex post facto objections, led to doctrinal development, which strengthened legal frameworks for future prosecutions and clarified individual obligations under international law.

Nuremberg Conclusion



The Tribunal established that grounding legal responsibilities in shared moral intuitions enhances compliance and legitimizes enforcement, especially in complex international situations. The Nuremberg Trials illustrate how natural law provides moral authority where formal legislation lags behind ethical imperatives. The Tribunal showcased the essential connection between justice and morality by holding individuals accountable for actions that violated fundamental human principles. Nuremberg illustrated that legal laws are most effective when linked with widely accepted ethical values, resulting in legitimate and lasting compliance. Its historical, doctrinal, and moral contributions continue to influence international law, human rights enforcement, and the idea that natural law principles are vital for bridging gaps between morality and legality. The Trials remain a key case for demonstrating how law, morality, and core human ideals can intersect to create justice even in the most challenging situations.

Foundational Status of the UDHR and ICCPR

Both the Universal Declaration of Human Rights and the International Covenant on Civil and Political Rights are regarded as the basic building blocks of today's international regime of human rights. The UDHR is commonly cited as the ethical basis of international human rights by scholars, having been proclaimed in 1948. In fact, Mary Ann Glendon calls the UDHR a common moral language that changed the global expectations of states' conduct, whereas Johannes Morsink describes it as a blueprint of the human rights covenants.

The ICCPR, adopted in 1966 and coming into effect in 1976, made the moral aspirations of the UDHR legally binding through a treaty. Together with the International Covenant on Economic, Social and Cultural Rights, the ICCPR makes legally binding the principles enunciated in the UDHR. The Office of the High Commissioner for Human Rights recognizes specifically that "the UDHR, together with the ICCPR and ICESCR, constitute the International Bill of Human Rights." Subsequent human rights treaties and conventions have almost exclusively used the language of the ICCPR.

Universal Declaration of Human Rights

This part explains how ideas of natural law were anticipated within a universal morality and resulted in the formation of the concept of human dignity that served as the basis of rights even before they were fully legalized.

The Universal Declaration of Human Rights is an essential document because it was one of the first documents to ratify international human rights laws. This document was prepared by delegates from across the world under the United Nations General Assembly and was established on December 10, 1948 (United Nations, 1948). It states fundamental rights of every person, which include things like freedom, human dignity, and justice.

The UDHR was adopted on December 10, 1948. As a set of positive law norms, the UDHR best finds its significance within the context of Natural Law. It is neither a treaty nor an international agreement. The UDHR is a statement of a "common standard of achievement" that should inspire legislations towards the realization of the fundamental moral principles. The fundamental premise expressed in the Preamble, "recognition of the inherent dignity and of the equal and inalienable rights of all members of the human family," implies that dignity and rights are pre-political realities recognized but not created by governments. By considering these recognitions as foundations of "freedom, justice and peace," the document conveys the idea of Natural Law that the legitimacy of laws rests on their degree of obedience to fundamental truths about human beings (Glendon 2001, 147).

As provided in Article 1, the moral anthropology of the Declaration is: "All human beings are born free and equal in dignity and rights. They are endowed with reason and conscience..." The basis of the rights in this context is reason and conscience, which is the foundation of Natural Law Theory in that everybody has



access to the principles of justice. It is in the concluding part where it is stated that individuals "should act towards each other in a spirit of brotherhood" that one gets the prelude to the subsequent discussions on the correlative duties. Equality based on reason and conscience provides the rationale for the recurrent statement in the UDHR that similar conditions should be treated in a similar manner under the law, not by virtue of the state's decree but owing to the prior moral status of the individuals who share it and for whom the law should treat them (Glendon 2001; Morsink 1999).

A powerful summary of the Natural Law model incorporated into the UDHR is provided by René Cassin, in which he compares the declaration to a Greek temple, with the foundation and steps (the Preamble), four pillars of rights, and a binding pediment. The rights, including both the civil and political freedoms and the social, economic, and cultural guarantees, are safeguarded in the columns; in the pediment (Articles 28-30), the rights are brought together by connecting them with a social and international order that can provide the conditions necessary for their realization. While the article itself provides a positive right to the social and international order, Article 29(2) limits any restrictions solely for ensuring "the just requirements of morality, public order and the general welfare in a democratic society. " The natural law elements of morality, order, and the common good are actually built into these restrictions of rights as well (Morsink 1999, 36–39). Furthermore, the UDHR embodies a teleological view of law, in which the role of the legal system is to create the "requisites for 'human flourishing,'" rather than merely avoiding the violation of people's interests. Indeed, Articles 25 and 26 of the UDHR identify several basic necessities necessary for an adequate standard of living—food, clothing, housing, medical care, and education aimed at developing "the human personality." Thus, interpreting the UDHR from the perspective of natural law, the declaration lays out the necessities that are required of justice for individuals and families so that freedom can be meaningful. This explains why the Declaration speaks of freedoms but also of concrete necessities. The Declaration assumes that actual freedom is contingent upon the requisites of society being proportional to human dignity (Glendon 2001; Morsink 1999).

Several other provisions also take for granted the presence of natural institutions and capacities that pertain to the state. For example, Article 16 values the family on the principle of "free and full consent," highlighting the moral agency of individuals and recognizing the importance of the family as an institution in the hierarchy of society. Article 18 provides justification for "freedom of thought, conscience, and religion" (including the right to conversion), affirming the person's role as a seeker of both truth and moral goodness. Article 27 attempts to strike a balance between cultural participation and respect for the ethical and material rights of authors, including the common good along with individual creativity. The essential idea is that the political authority should serve as a means of enhancing those earlier goods, not as an end that should overshadow them (Glendon 2001; Morsink 1999).

Article 1 sets forth the doctrine of moral equality, while Article 29 states the concept of "duties and limits": the individual "is under certain duties towards the community," and any limitations upon his rights are considered "justifiable only if such limitations are determined by requirements of morality, public order and the general welfare" and never aim at destroying the rights of the individual (Article 30). Such a stance does not support the ideas of voluntarism, which is against the connection of the legal system and moral philosophy, and the theory of rights absolutism, in which the right itself can become a tool to destroy its very foundation.

Lastly, there is the UDHR's resonance with the theory of Natural Law, which goes hand in hand with drafting pluralism. For instance, the committee included Thomist-Christian thought, liberalism, and Confucianism among other doctrines. According to Jacques Maritain, it was possible for the framers to "agree on the list" despite their disagreements on the practical foundation of moral judgments and their attempts not to rely on metaphysics of any one doctrine (Glendon 2001). Scholars warn against crediting Natural Law for the UDHR because several natural-law philosophers who were skeptical of human rights were against the UDHR at that time. However, the language used by the UDHR of inherent dignity, reason and conscience, the common good, and just limits reveals that Natural Law concepts were strengthened through ecumenical philosophical collaboration.



UDHR shows how principles of natural law could become widely accepted on a normative basis without the requirement of legal enforceability. The focus on inherent dignity, moral equality, and responsibility towards the community enabled universal acceptance and internalization of the standards of human rights. It therefore reinforces the point that moral authority is indispensable for compliance even prior to legislation.

Genocide Convention

This portion elucidates how an outrageous moral outrage has been quickly turned into law that binds nations.

The Convention on the Prevention and Punishment of the Crime of Genocide, passed in 1948, is perhaps one of the best examples of the process of transforming ideas of natural law into international positive law. Lemkin, who coined the term 'genocide', argued that genocide was inherently morally evil and, therefore, ought to be made illegal by international law irrespective of whether states were in agreement or not. As per the convention, genocide refers to any act done with the purpose to commit the destruction of national, ethnic, racial, or religious groups; it is an offense against humanity.

The Genocide Convention is considered one of the bedrock documents by scholars. William Schabas calls it the first international human rights treaty, while Antonio Cassese stresses its significance in the development of the concept of jus cogens norms. Payam Akhavan argues that the law against genocide is the basis of international human rights law. The International Law Commission has confirmed that the ban on genocide is a peremptory norm of international law.

The Genocide Convention is an example of how clear morality narrows the distance between recognition in natural law and codification in positive law. In contrast to the Nuremberg Trials, where enforcement precedes codification, genocide was recognized as a rule of law quickly due to moral agreement.

Hypothesis Application: Genocide Convention

There is strong support for H1 under the Genocide Convention. The universal nature of genocide being a crime against humanity helped the convention to gain widespread acceptance and enduring normative validity.

H2 gains only weak support, as debates regarding the intent and scope have not affected the basic prohibition against genocide. H3 does not receive any support as cultural diversity cannot be cited as a reason for non-compliance.

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International Covenant on Civil and Political Rights (ICCPR)

This chapter will provide examples of how natural law ideals have been transformed into treaty obligations. This hybrid model brings to the fore the advantages and disadvantages of positivist enforcement procedures.

The International Covenant on Civil and Political Rights (ICCPR) was adopted in 1966 and is the end product of attempts to transform the Universal Declaration of Human Rights' ethical objectives into a binding international treaty. Though its composition is characterized by positivism through state consent in the form of signing and ratification and the creation of the Human Rights Committee to ensure adherence, the Covenant's substance is predominantly shaped by natural law ideals.

The ICCPR preamble begins with the affirmation that the rights enshrined by the Covenant derive from "the inherent dignity of the human person." This formulation takes an archetypical stance on natural law, where the existence of the rights precedes and transcends state consent; what is being institutionalized is nothing other than the pre-existing reality of the rights. Instead of creating rights through legislation, the Covenant



rests on a moral ontology that takes human dignity and associated rights as facts that need recognition and protection within the legal system. The ICCPR is thus an instance of a natural rights legal system where the legitimacy of the law depends on its accordance with human dignity and justice.

Natural Law as Source, Positivism as Form.

There is an obligation on states under the Covenant to respect and ensure civil and political liberties such as freedom of speech, freedom from torture, fair hearing, and equality before the law (OHCHR 1966). The clarity of these legal duties notwithstanding, their frequent violation raises a key question regarding international human rights laws: the reasons for non-compliance when these duties have been legally recognized. This brings out the fact that legal obligations do not guarantee compliance unless there is moral commitment to the rights involved.

According to Article 1(1) of the ICCPR, “All peoples have the right of self-determination. By virtue of that right, they freely determine their political status and freely pursue their economic, social and cultural development” (UN 1966). In effect, this article embodies one of the central principles of natural law – that political power emanates from individuals’ capacity for morality. As per the ICCPR, civil and political rights can be traced back to human beings’ natural ability to make choices and think.

On the other hand, Article 6 of the ICCPR states that “Every human being has the inherent right to life.” It is worth noting that use of the word “inherent” highlights the ethical fact that the right to life pre-exists the covenant. However, it is crucial to note that Article 6 not only proscribes arbitrary deprivation of life but also obliges the state to make efforts to ensure the safety of individuals’ lives whenever there is an identifiable risk. The latter idea is aligned with natural law jurisprudence since the preservation of life constitutes an essential aspect of natural morality, thereby triggering positive duties of care by the state.

This is demonstrated through the case of the Italian shipwreck, which highlights the impact that the principles of natural law have on interpreting the duties of a state based on a positivist international treaty. According to the judgment made in 2021 by the Human Rights Committee, Italy was at fault for its failure to undertake appropriate coordination or prompt action to save lives. Even though Italy had argued that it lacked jurisdiction to take any actions since it had no direct control over the vessel, it became clear that it had the capacity to undertake any action and knew about the looming danger to lives.

However, Article 2(1) of the ICCPR enhances the moral principle of responsibility by stating that states must “respect” and “ensure” the rights set forth in the Covenant. The obligation to ensure implies that mere formality, such as the ratification or submission of reports, cannot suffice. In natural law theory, authority implies responsibility, and hence, by exercising authority, one has an inherent obligation to preserve the fundamental values necessary for preserving human dignity, i.e., life, freedom, and equality.

Even with its robust moral and legal basis, the ICCPR is still subject to compliance problems. The gap cannot be accounted for by theological uncertainty or insufficient institutions. Instead, this points to an issue of lack of internalization, where countries give their consent to the positivist version of the agreement without fully endorsing the moral responsibilities underlying it in natural law terms. In terms of compliance, the ICCPR shows how limited positivist systems of consent can be when the duties seem to be outside, technical, or political.

ICCPR is thus defined as an example of a hybrid treaty. Moral justification of the ICCPR is based on principles like inherent dignity, moral equality, and sanctity of life drawn from natural law. However, the efficiency of the ICCPR lies in its reliance on the state-centered approaches of legal positivism, which causes a contradiction leading to the compliance gap under discussion here. The ICCPR provides ample evidence to support the hypothesis that natural law-based foundations result in improved compliance because they frame the obligation to respect rights as a moral one, not just a legal one. In addition, the inconsistency of state compliance may serve to substantiate hypothesis two by providing an illustration of how ambiguity in the interpretation of the moral aspect could be the cause of non-compliance.



In ICCPR, it is evident that although legalization can help enhance human rights, compliance will depend on the states adopting the morality behind their adopted human rights laws. The constant problem with compliance highlights the weakness of positivist consent, especially in cases where moral obligation does not exist. This is an example where the paper's argument that natural law facilitates compliance because it turns legal duties into moral obligations stands out.

Cross-Case Analysis

This same imperative structure becomes apparent in each case. As evidenced by the Nuremberg Trials, moral legitimacy can serve as a substitute for legal legitimacy where legislation fails to live up to morality. Moral consensus expedites and strengthens codification through the Genocide Convention. The UDHR proves how moral soundness encourages universal acceptance despite the lack of enforcement measures. Finally, the ICCPR highlights how mere legal enforcement is inadequate without moral commitment.

As such, all of the cases strongly validate H1, provide some validation to H2, hold very little bearing on H3, and negate H4. It is clear that moral legitimacy constitutes both a necessary and a sufficient condition for compliance.

But there are numerous serious criticisms made by the critics. First, the concept of "nature" is very ambiguous. "Nature" may be subjectively understood in the most varied ways by humans. Appealing to the concept of "nature" has historically been a source of justification of injustice, from Aristotle's support of slavery to racial and sexual hierarchies. Second, extending the criticisms of David Hume, the "Is-Ought Problem" is raised to challenge the validity of deriving a moral prescription from an observation of nature. Finally, the criticism related to enforcement. Without any clearly defined basis of natural law, it seems that such law may be simply seen as "sentimental fictions" incapable of being applied in law and politics. Given such criticism, many scholars and human rights activists today have turned away from the discussion of natural law, considering it philosophically controversial, outdated, or even irrelevant.

The Nuremberg trials present convincing support for H1 since they show that it was possible to comply based on moral legitimacy despite not having legal statutes previously. The UDHR strengthens H1 because it presents the idea that there exists universal endorsement of norms through moral agreement and not just through enforcing these norms. In the case of the ICCPR, it shows that the propositions in H1 and H2 are partially supported since moral ambiguity facilitates compliance despite being based on natural laws.

Recommendation

Following the analysis of the above case studies, this section explores potential solutions for increasing compliance with international human rights responsibilities through natural law concepts. Moral legitimacy was found to be a critical aspect of effective compliance with international law. Thus, international organizations, governments, and policy makers may consider certain strategies in order to enhance the sense of universality and moral duty in relation to international human rights law.

It is necessary to emphasize that monitoring agencies within international human rights organizations should incorporate natural law and moral aspects into their findings, conclusions, and General Comments. By defining compliance as the fulfillment of a morally obligatory task rather than a mere procedural one, these bodies may help states internalize these principles and comply with human rights laws in the future. For instance, the Italian shipwreck can serve as a good example for demonstrating that states have an imperative obligation, besides their legal duty, to save lives during such situations. This method is aligned with Raustiala's normative alignment strategy and Koh's internalization approach.

Any human rights treaty and domestic laws should refer to natural law concepts and emphasize moral principles in their wording. It will allow defining human rights as naturally strengthening the moral foundation



of rights. For example, treaties could specify that rights “derive from inherent human dignity” or “exist independently of state consent.” This makes it clear that legal obligations are based on universal moral principles rather than being arbitrary. By closing the gap between moral legitimacy and legal codification, this method might increase the perception of responsibilities as naturally binding, increasing compliance.

Training courses for diplomats, judges, law enforcement agents, and other state officials must include not only the legal obligations but also the moral aspect of human rights and the principle of natural law. Case study examples of the use of natural law to make the responsible state act may include the example of Nuremberg trials or more contemporary cases, such as maritime rescue requirements according to the ICCPR. Knowledge about the moral foundations of human rights will make state officials understand their moral obligations better and will result in proactive compliance with human rights requirements.

Public knowledge about human rights commitments is crucial for building moral credibility. Campaigns focusing on the notion that the fulfillment of human rights is our common moral obligation, especially when it comes to disadvantaged groups of the population, children, and immigrants, would apply social and political pressure to states. It would give citizens one more tool of persuasion along with laws for protecting their rights and interests.

International judicial bodies and enforcement agencies should focus on cases where violations of international human rights law are accompanied by violations of universally accepted moral principles. The latter could be especially helpful when it comes to situations when the formal legal codification is vague or insufficient.

To strengthen the link between moral legitimacy and compliance, comparative and quantitative studies should look at treaties or legal instruments that clearly contain natural law principles versus those that do not. Measuring disparities in compliance rates and enforcement results can give empirical support for the theoretical framework described in this paper and guide future legal and policy design.

Conclusion

This paper does not agree with the fact that incorporating natural law principles promotes compliance with civil and political rights by converting legal responsibilities into moral duties that states and individuals are more inclined to internalize and uphold. In the end, the history of international human rights law demonstrates that legality alone has never been sufficient to protect human dignity. From Nuremberg’s moral reckoning to the UDHR’s aspirational authority, the peremptory prohibition of genocide, and finally the ICCPR’s hybrid legal-moral structure, a consistent pattern emerges where law is aligned with deeply rooted moral principles, it gains not only authority but also legitimacy, and where legitimacy exists, compliance becomes more likely, more durable, and more internalized. The Italian shipwreck tragedy, which sparked this investigation, is the typical example with devastating clarity of what happens when legal formalism trumps moral responsibility: hundreds of lives are lost not because rescue was impossible, but due to the fact that obligation was interpreted narrowly rather than compassionately. This paper disagrees that natural law does not compete with international human rights law but rather complements it by providing the moral underpinning that changes written norms into lived commitments and legal obligations into ethical imperatives. While natural law is not a utopia and cannot eradicate political self-interest, ambiguity, or power disparities, it is an essential component of any human rights regime that wants more performative conformity. Without moral internalization, treaties become paperwork, and without moral legitimacy, institutions become procedural shells. The great triumphs of the modern human rights project sprang not from technical legalism, but from moral anger, moral clarity, and moral commitment, and it is precisely this moral core that must continue to drive the interpretation, growth, and implementation of international law. If human rights are to be more than just written promises, if they are to serve as real protections for real people in real danger, international law must continue to speak not only in the language of jurisdiction and



procedure, but also in the deeper language of human dignity, shared humanity, and moral duty which natural law has always sought to articulate.

References

Austin, J. (1995). *The province of jurisprudence determined* (W. E. Rumble, Ed.). Cambridge University Press. (Original work published 1832)

Civil MRCC. (2026). 11 October 2013 shipwreck trial. Retrieved January 7, 2026, from <https://civilmrcc.eu/legal-fragment/11-october-2013-shipwreck-trial/>

Glendon, M. A. (2001). *A world made new: Eleanor Roosevelt and the Universal Declaration of Human Rights*. Random House.

Green, L., & Adams, T. (2024). Legal positivism. In E. N. Zalta & U. Nodelman (Eds.), *The Stanford Encyclopedia of Philosophy* (Winter 2024 ed.). <https://plato.stanford.edu/entries/legal-positivism/>

Hart, H. L. A. (1961). *The concept of law*. Clarendon Press.

Koh, H. H. (1997). Why nations obey. *The Yale Law Journal*, 106(8), 2599–2659.

Morsink, J. (1999). *The Universal Declaration of Human Rights: Origins, drafting, and intent*. University of Pennsylvania Press.

OHCHR. (2021, January 27). Italy failed to rescue more than 200 migrants, UN committee finds. <https://www.ohchr.org/en/press-releases/2021/01/italy-failed-rescue-more-200-migrants-un-committee-finds>

Pro Asyl. (2022, December 19). Landmark court ruling on 2013 shipwreck: Italian coast guard and navy responsible for deaths of 268 refugees. <https://www.proasyl.de/en/pressrelease/landmark-court-ruling-on-2013-shipwreck-italian-coast-guard-and-navy-responsible-for-deaths-of-268-refugees/>

Raustiala, K. (2000). Compliance & effectiveness in international regulatory cooperation. *Case Western Reserve Journal of International Law*, 32(3), 387–440.

Schachter, O. (1977). The twilight existence of nonbinding international agreements. *American Journal of International Law*, 71(2), 296–304.

United Nations. (1948, December 9). *Convention on the prevention and punishment of the crime of genocide*. United Nations Treaty Series, 78, 277.



Intergenerational Equity in Climate Governance

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Abstract

This paper examines how the principle of intergenerational equity moves from treaty language to domestic climate policy. It first derives a legal benchmark from the Stockholm Declaration, the UNFCCC, and the Paris Agreement's preambular reference to intergenerational equity and Article 4.19 on long-term low-emission strategies. It then tests the benchmark against five cases at the core of contemporary governance, the EU Carbon Border Adjustment Mechanism (CBAM), Germany's post-Neubauer carbon-budget framework, South Korea's Constitutional Court ruling requiring year-by-year targets, Canada's 2025 pause of the federal consumer fuel charge, and the linked California–Québec cap-and-trade market. The analysis adopts three metrics, temporal alignment, credible commitment, and avoidance of burden-shifting, and reads official texts, auction outcomes, and court decisions. The findings support the central hypothesis that integration of the intergenerational principle is strong in international law, while domestic embedding remains uneven and fragile, improving where courts or automatic policy levers constrain back-loading. Policy implications include independent carbon-budget committees, annual sector pathways with “comply-or-tighten” triggers, cap-and-trade design that restores scarcity when prices clear at the floor, and CBAM roadmaps that link border pricing to plant-level investment. These institutional choices convert treaty ideals into durable, near-term delivery.

Keywords

Intergenerational equity; Climate governance; Carbon budgets; Long-term low-emission strategies (LTS); CBAM; Cap-and-trade

Introduction

Global climate policy now unfolds against two converging curves. First, the population is increasing significantly. United Nations data indicate the world population will rise from eight billion today to about 9.7 billion by 2050, with two-thirds living in cities and most growth in regions already facing heat extremes and food-system stress (UN DESA, World Population Prospects 2022). Second, air pollution is accelerating. According to the IPCC, at today's emission rate the remaining carbon budget compatible with a 1.5 °C limit could be exhausted in less than seven years (IPCC, AR6 Synthesis Report 2023, 25). When these trends meet, they sharpen an old ethical question: what do people alive now owe to those who will inherit a hotter and more crowded planet?

Intergenerational equity offers a principled answer. Edith Brown Weiss frames each generation as a trustee that must pass on comparable options, environmental quality, and resource access. This concept has travelled a long path, beginning as aspirational language in the 1972 Stockholm Declaration and becoming explicit treaty text in the 2015 Paris Agreement, whose preamble references “intergenerational equity” and whose Article 4.19 calls on Parties to submit long-term low-emission strategies (UNFCCC, Paris Agreement). Even so, domestic uptake is uneven. German and South Korean courts have used the principle to compel earlier mitigation, while Canada's 2025 pause of its household carbon price shows how political short-termism can still override future-oriented goals.

This study asks a question, how does the intergenerational principle inform climate governance, and why does it take hold in some jurisdictions but not in others? The inquiry proceeds in two



steps. First, it extracts a legal benchmark for intergenerational equity from the Stockholm Declaration, the UNFCCC, and the Paris Agreement. Second, it tests that benchmark against five contemporary policy instruments: the EU Carbon Border Adjustment Mechanism, Germany's post-Neubauer carbon-budget framework, South Korea's court-mandated annual targets, Canada's price-pause episode, and the linked California–Québec cap-and-trade market. Tracing where the principle is merely proclaimed and where it becomes enforceable budgets, automatic price floors, or judicial guardrails reveals the design choices that move a treaty ideal into durable domestic action—an outcome made increasingly urgent as both population and temperature curves bend upward.

Literature Review

Definition of Intergenerational Equity

Intergenerational equity names the normative claim that each generation holds the Earth “in trust” for those who come after it. Edith Brown Weiss crystallises the idea into three duties—preserving comparable options, comparable quality, and comparable access—so that future people inherit at least the same ecological capital that we do (Weiss). This partnership model treats succeeding cohorts as rights-holders rather than passive beneficiaries, supplying the moral centre for contemporary debates about climate-change mitigation and resource use.

Importance of Intergenerational Equity

The principle's weight in international law can be traced back to the Stockholm Declaration, which recognises a “solemn responsibility to protect and improve the environment for present and future generations” (United Nations, Stockholm Declaration Principle 1). By 2015, the Paris Agreement elevated that concern, explicitly citing “intergenerational equity” in its preamble and urging Parties to adopt long-term low-emission strategies that look well beyond standard five-year economic cycles (UNFCCC, Paris Agreement Preamble; art. 4.19). Together, these instruments frame climate change not merely as a present-day externality but as a justice problem spanning centuries.

Evolution of the Concept

Early UN texts treated the environment mainly as a storehouse of resources for development; the Sustainable Development Goals still echo that tension, invoking “future generations” while foregrounding poverty eradication for today's poor (Spijkers 603). Yet a jurisprudential turn is underway. Pedersen and Sulyok describe a wave of “future-generations litigation” in which courts convert soft-law aspirations into enforceable duties, expanding states' “future-minding obligations” (Pedersen & Sulyok 211). Slobodian tracks similar trends in public-trust and constitutional cases where judges treat the unborn as a legally cognisable public, pressing governments to integrate their interests in planning and permitting (Slobodian 584).

Multiple Analytical Lenses

Legal-philosophical. Weiss's trustee model supplies the foundational ethics; recent litigation shows how courts operationalise it. Behavioural. Halali and Perez find that ordinary citizens readily vote for commitment devices that bind successors, exhibiting “long-sighted altruism” that preserves resources across experimental generations (Halali & Perez 6). Regulatory-economic. Okrent unpacks the United States' uneven risk standards—no discounting of radioactive-waste harms for 10,000 years, yet far laxer rules for equally persistent chemicals—to illustrate how the



absence of a coherent long-horizon philosophy distorts cost-benefit analysis (Okrent 463). Policy-instrument. Schuppert shows that “economy-friendly” tools such as cap-and-trade or carbon taxes, designed around short-run efficiency, seldom deliver emission cuts or equitable burden-sharing strong enough to satisfy a “thicker account of intergenerational justice” (Schuppert 308–10).

Environmental-policy frameworks and their treatment of intergenerational equity

At the multilateral level, the Paris Agreement urges Parties to lodge “long-term low greenhouse-gas emission development strategies” (LTS) that look well past mid-century, thereby inserting an explicit future-oriented logic into international climate law (UNFCCC art. 4.19) . Yet the same treaty structures action around five-year nationally determined contributions that are updated in step with electoral cycles, tempting governments to privilege short-run competitiveness over deeper decarbonisation commitments (UNFCCC art. 4.9) . The result is a hybrid regime: visionary in rhetoric, but operationalised through iterative pledges that can lag behind the science.

Within domestic regulation, contrasting risk standards expose how discounting practices encode generational priorities. In the United States, the Environmental Protection Agency forbids any discounting of potential health effects from high-level radioactive waste for ten millennia, whereas equally persistent chemical hazards face far laxer rules, a disparity Okrent attributes to the absence of “a broad guiding philosophy” for very-long-term risks (Okrent 878). The agency’s stance—protect future societies as stringently as the present—imposes immense present-day costs, but only for selected hazards, highlighting an equity gap both across pollutants and between generations (Okrent L48-L56).

Market instruments such as cap-and-trade and carbon taxes were designed for economic efficiency, not justice across centuries. Schuppert shows that most existing schemes are promoted precisely because they are “economy-friendly,” yielding modest emission cuts and free permit allocations that keep prices—and therefore political pain—low today while postponing harder choices (Schuppert 308). Their annual pricing cycles and grandfathered allowances embed a presentist bias that contradicts a “thick” conception of intergenerational justice, which would instead front-load mitigation to secure ecological space for the unborn (Schuppert 313).

Finally, the courts have emerged as a corrective venue. Pedersen and Sulyok document how “future-generations litigation” repurposes soft-law aspirations as binding constitutional and human-rights duties, thereby extending states’ “future-minding obligations” and shrinking the discretionary space left to short-term politics (Pedersen & Sulyok 470–471). Recent judgments—from Germany’s Neubauer to the European Court of Human Rights’ 2024 KlimaSeniorinnen ruling—explicitly bar governments from off-loading disproportionate mitigation burdens onto young or unborn citizens, forcing policy timetables to respect carbon budgets that span well beyond the next fiscal year (Pedersen & Sulyok 473)

Hypothesis

The analysis proceeds from three alternative hypotheses about the legal status and practical reach of the intergenerational principle. The first hypothesis is that the idea still resides chiefly in the realm of aspiration: treaty preambles and soft-law declarations serve as moral signposts rather than enforceable commands, and domestic legislation has yet to convert those signposts into binding duties. The second hypothesis adopts a stronger reading. It holds that the principle now sits at the core of contemporary climate law, anchored in the Paris Agreement’s requirement for long-term low-emission strategies, and is already mirrored in national instruments such as statutory emissions budgets, carbon taxes, and economy-wide cap-and-trade programmes. If this claim is correct, treaty language and day-to-day policy tools should align closely to preserve the



option space of future generations. The third, intermediate hypothesis maintains that intergenerational equity is indeed codified internationally but remains only partially or unevenly embedded at home; governments invoke the principle in negotiations and NDC submissions, yet domestic implementation often lags through weak price signals, heavy reliance on offsets, or sectoral loopholes, and real alignment appears only where courts or automatic policy levers force the issue. The case studies that follow test which of these competing hypotheses best fits current practice.

Results and Discussion

Case Study

Methodology

This study unfolds in two stages. First, it establishes a legal benchmark for intergenerational equity by reading three foundational instruments in sequence. The 1972 Stockholm Declaration introduces a “solemn responsibility” to protect the environment for present and future generations. The 1992 UN Framework Convention on Climate Change widens that idea into treaty language, and the 2015 Paris Agreement makes it explicit by naming “intergenerational equity” in its preamble and by obliging Parties, in Article 4.19, to file long-term low-emission strategies. A close textual analysis of these documents shows a clear through-line: present generations must preserve comparable options, environmental quality, and access for those who follow and must avoid back-loading mitigation into later decades.

The second stage tests how far that benchmark travels into domestic practice by examining five policy instruments that sit at the centre of current climate governance. The EU’s Carbon Border Adjustment Mechanism (CBAM) carries the Paris time horizon into trade by equalising carbon prices on imports and phasing out free allowances. Germany’s Neubauer ruling and the subsequent Climate Protection Act amendment translate the trustee logic into a court-enforced carbon budget. South Korea’s 2024 Constitutional Court decision overlays year-by-year targets on an NDC that had relied heavily on overseas reductions. Canada’s 2035 NDC and the 2025 pause of the consumer fuel charge test the fragility of price-based commitment devices. Finally, the linked California–Québec cap-and-trade system illustrates how a rising auction floor can protect a minimum scarcity signal yet still allow generous banking and offsets.

Each case is read against three metrics that flow directly from the legal standard: temporal alignment, measured by the presence of dated caps or annual budgets; credible commitment, assessed through automatic floors, cancellation rules or judicial enforcement; and avoidance of burden-shifting, captured by leakage controls, offset quality and the domestic share of reductions. Performance on these metrics, documented with official data, auction results and court materials, reveals how fully the intergenerational principle has moved from treaty text to the day-to-day mechanics of national climate policy.

Intergenerational Equity in International Legal Regimes

Intergenerational equity provides the normative baseline for judging whether present policies preserve comparable options, quality, and access for future people (Weiss 2008). The Paris Agreement’s preamble expressly recognizes “intergenerational equity” and, together with Article 4.19 on long-term low-emission strategies, pushes Parties to look beyond electoral cycles toward systemic decarbonization (UNFCCC, Paris Agreement, preamble; art. 4.19). That trajectory rests on an earlier foundation in the Stockholm Declaration, which framed a “solemn responsibility” to protect the environment for present and future generations and called for safeguarding natural resources against future exhaustion (United Nations, Stockholm Declaration, Principles 1–2, 5). Taken together, these instruments embed the future-minding logic in international law; the open question is whether domestic instruments truly carry it through.



EU Carbon Border Adjustment Mechanism (CBAM)

In brief, CBAM(Carbon Border Adjustment Mechanism) is the EU's carbon border pricing mechanism that requires importers of selected carbon-intensive goods to pay a charge linked to the EU ETS(Emission Trading System) so that imports face the same carbon cost as EU producers. The EU's CBAM operationalizes a simple but far-reaching idea. Under this regime, imports of carbon-intensive goods face a carbon price equivalent to that paid by EU producers under the EU Emissions Trading System. After a 2023–2025 transitional phase of reporting, the definitive regime begins in 2026 and dovetails with the phase-out of free EU ETS allowances through 2034, initially covering cement, iron and steel, aluminum, fertilizers, electricity, and hydrogen. Importers buy CBAM certificates priced by the weekly EU ETS average, receive credits for any explicit carbon price already paid abroad, and comply with anti-circumvention rules alongside a stated aim to support developing countries' decarbonization efforts (European Commission; EUR-Lex; European Parliament).

This design matters because it directly targets carbon leakage, the tendency of firms to offshore production to weaker regimes and, in doing so, shifts mitigation burdens forward in time and onto other jurisdictions' future publics rather than reducing absolute emissions today. By hard-wiring price equivalence at the border, CBAM raises the expected return on cleaner production in exporting countries and reduces a key strategic reason for delay at home. That salience is structural because, without CBAM, tightening the EU ETS risks eroding the bloc's industrial base and political support, which in turn invites rollbacks that defer mitigation to later cohorts.

Intergenerational equity is explicit in the treaty backdrop, since Paris urges "long-term low greenhouse gas emission development strategies". CBAM functions as a commitment device that ties present choices to a trajectory consistent with conserving comparable options and environmental quality for later generations (UNFCCC, Paris Agreement; Weiss). For the hypothesis tested in this paper, CBAM supports the claim that intergenerational equity is integrated at the international and EU-level rulemaking stage, while domestic embedding across Member States remains uneven and depends on complementary national policies. It therefore acts as a partial medium from principle to practice rather than proof of consistent domestication.

Germany: NDCs and constitutional guardrails

Germany's Federal Constitutional Court in Neubauer reframed climate protection as a problem of "intertemporal freedom" and required lawmakers to set clearer post-2030 constraints, which catalyzed the 2021 amendment tightening the 2030 target to at least 65 percent below 1990 and mandating climate neutrality by 2045 (Climate Case Chart). The Court found that the earlier Climate Protection Act set detailed annual budgets only up to 2030 and left reductions after 2030 largely undefined. That design risked pushing very steep cuts into the 2030s and 2040s and thereby burdening younger and unborn citizens' freedoms in a way that conflicted with constitutional guarantees, so the legislature was instructed to spell out the post-2030 pathway more precisely (Climate Case Chart). The Court's reasoning was explicitly intergenerational, aiming to prevent today's cohorts from exhausting the remaining carbon budget and constraining tomorrow's freedoms by back-loading mitigation (Climate Case Chart).

The policy significance is twofold. First, the judgment constitutionalized the carbon-budget logic by preventing the state from loading disproportionate mitigation onto later years, which would otherwise spend the budget early and squeeze future freedoms. Second, subsequent political choices have risked loosening those constraints. In 2024, a reform replaced binding sectoral ceilings with an aggregate target, which diluted enforceability precisely where transport has repeatedly missed its marks (Reuters; German Federal Government). Germany's implementation gap has concrete causes. Transport emissions are sticky because of commuting patterns, slow fleet turnover, and contested fuel standards, and weaker sectoral guardrails make it easier to delay the hard work in that sector. Taken together, this sequence—from constitutional findings to



statutory tightening and then partial softening—sets up the core question of who bears which share of the remaining budget, and when.

Against that backdrop, intergenerational equity is directly engaged. A court-imposed duty to distribute mitigation fairly over time aligns with the Paris Agreement’s intergenerational language and with Weiss’s trustee model of passing on comparable environmental quality, converting an ethical directive into justiciable constraints on near-term policy design (UNFCCC, Paris Agreement; Weiss). For the hypothesis tested here, Germany shows strong legal integration of the intergenerational principle but uneven domestic embedding in delivery. In other words, the norm is secured in law, yet consistent implementation in day-to-day policy remains incomplete.

Republic of Korea: NDC ambition and judicial oversight

South Korea’s NDC sets a headline goal of 40 percent below a 2018 peak by 2030. After accounting for land use and overseas components, roughly 32 percent is slated to occur domestically, which is why independent assessments rate the package “Insufficient” for a 1.5 °C pathway (Climate Action Tracker, South Korea). The policy rests on the Framework Act on Carbon Neutrality, a national ETS covering major emitters, and sectoral plans in power, industry, buildings, and transport. It also allows the use of international units to close part of the gap on paper (Climate Action Tracker; UNFCCC).

Why this matters needs to be clear in policy terms. The 2018 baseline is high for an industry-heavy economy, so a 40 percent cut implies large absolute reductions even before you look at the domestic share. Domestic measures have been slow to take effect because coal remains significant in the power mix, industrial energy demand is hard to abate, and retail electricity tariffs have been politically constrained during fuel-price spikes. These factors mute the pass-through of a carbon signal and slow the switch to clean power (Ember).

Judicial oversight tightened the trajectory in 2024. The Constitutional Court ordered the government to set year-by-year interim targets through mid-century and to strengthen planning to protect fundamental rights from climate harms. That ruling reduces the scope for back-loading and pushes additional action into this decade (Reuters).

Intergenerational equity is engaged at two levels. Paris requires long-term strategies that protect future generations, and Weiss’s trustee model demands the preservation of comparable options and environmental quality (UNFCCC, Paris Agreement; Weiss). Korea’s case supports the paper’s hypothesis. International integration is clear, and legal domestication has advanced through the court’s order, yet practical domestic embedding remains incomplete because implementation still leans on non-domestic reductions and delayed structural change at home (Climate Action Tracker; Reuters; Ember).

Canada: NDC signaling and carbon price credibility

Canada submitted a 2035 NDC of 45–50 percent below 2005, aligning its long-term pathway with a narrowing global carbon budget (UNFCCC NDC Registry). In April 2025, the federal government then set the federal consumer fuel-charge rate to zero “until further notice,” while keeping the industrial Output-Based Pricing System in place and citing affordability pressures and a focus on major emitters (Department of Finance Canada). The federal backstop has two pillars. One is the household- and small-business fuel charge that applies where provincial systems are not equivalent, and the other is the output-based system that prices large industrial facilities. Pausing the former removes the broad economy-wide signal that was designed to complement the industrial system and to keep all sectors contributing over time (UNFCCC NDC Registry; Department of Finance Canada).



This change matters because it weakens the expectation that households and small firms will steadily adjust investment and consumption decisions, which is how policy credibility and long-lived private investment take root. The main driver is political economy rather than new evidence about pricing effectiveness. When inflation and energy bills rise, consumer-facing carbon charges become a quick lever for relief, even though the pause undercuts the intertemporal commitment that decarbonization investment cycles rely on (Department of Finance Canada).

Intergenerational equity is at stake as a question of credible commitment. Behavioral evidence suggests that societies support devices that bind both successors and themselves because such devices sustain cooperation across generations (Halali and Perez). Weakening the consumer price increases the risk that future governments or sectors will defect, which shifts costs forward and cuts against the Paris preamble's intergenerational commitment and the trustee duty to preserve comparable environmental quality (UNFCCC, Paris Agreement; Weiss). Read against the paper's hypothesis, Canada exemplifies clear international integration through its 2035 NDC but inconsistent domestic embedding when a core commitment device is suspended. In short, the norm is acknowledged internationally while its day-to-day implementation at home remains fragile.

California–Québec linked cap-and-trade

The California–Québec program links two markets under a single declining cap and runs joint quarterly auctions. It covers electricity imports, large industrial facilities, and fuel distributors, and it allows limited banking of unused allowances and a small quantity of offsets. Auctions include an Auction Reserve Price that rises each year by inflation plus five percent, and there are additional price-containment tiers that release extra allowances at higher trigger prices. In May 2025 the joint auction cleared at the floor price of USD 25.87, the first floor-clearing since 2020, which signals that demand met the minimum allowed price rather than bidding above it (CARB; ICAP; S&P Global Commodity Insights).

Companies accumulated sizable banks of unused allowances in earlier years and can spend them now. Offset rules still allow some portion of compliance to come from credits rather than allowances. Several complementary policies, such as renewable and clean-fuel standards, reduce covered demand and make the cap easier to meet. Post-2020 cap tightening has also been gradual. Together these factors keep the market near the floor and indicate that the cap, not the price floor, is often the non-binding element (CARB; ICAP).

When the market clears at the minimum, more of the cumulative carbon budget is effectively used today and fewer options remain for later cohorts. A stronger intergenerational alignment would come from tightening the cap on a dated schedule, reducing and upgrading offsets, and raising the real-term floor if floor-clearing persists. Read against the paper's hypothesis, this case shows partial domestic embedding of the intergenerational principle. The architecture acknowledges future-minding duties and keeps a baseline price in place, yet delivery is uneven because the cap is not reliably binding. That pattern supports the claim that international integration is clear while consistent domestic implementation remains incomplete (Weiss; UNFCCC, Paris Agreement; CARB; ICAP; S&P Global Commodity Insights).

Cross-Case analysis

The case studies support the hypothesis that intergenerational equity is clearly integrated in international climate law, yet unevenly embedded in domestic policy. The legal anchor is firm. The Paris Agreement names "intergenerational equity" and requires long-term low-emission strategies, and Weiss's trustee model specifies duties to preserve comparable options, quality, and access for future people (UNFCCC, Paris Agreement, preamble; art. 4.19; Weiss 2008).



Read together, the cases show a consistent pattern. CBAM carries the treaty's long-horizon logic into a border rule that deters leakage and anchors the EU pathway, but it evidences only partial domestication because Member-State uptake still depends on complementary national policies (European Commission; EUR-Lex; European Parliament). Germany's Neubauer decision constitutionalizes a future-minding duty and prompted statutory tightening, while the later move from sectoral ceilings to an aggregate target shows that delivery can soften even under a strong legal frame (Climate Case Chart; Reuters). Korea's 2024 ruling imposed year-by-year targets and strengthened legal domestication, yet continued reliance on non-domestic reductions and slower structural change at home reveal incomplete practical embedding (Climate Action Tracker; Ember; Reuters). Canada's 2035 NDC signals international integration, whereas the 2025 suspension of the consumer fuel charge weakens the domestic commitment device and leaves implementation fragile (UNFCCC NDC Registry; Department of Finance Canada). The California–Québec system preserves a minimum scarcity price through a rising floor, but repeated floor-clearing indicates the cap is not reliably binding and that offsets and banking still dilute the intertemporal constraint (CARB; ICAP; S&P Global Commodity Insights).

Taken together, international law sets a clear standard for protecting future generations, and domestic realization is most evident where policy architecture or courts constrain back-loading of effort. Where those constraints are thin, politics tilts toward the present and shifts burdens forward in time. The overall record, therefore, confirms the paper's hypothesis: integration is strong at the international level, while consistent domestic embedding remains uneven across jurisdictions.

Recommendations

Independent Carbon Budget Committee

Germany's post-Neubauer reform still lets future legislatures loosen sector limits, and Korea's court-imposed annual targets have yet to be written into statute. Canada showed how a single budget cycle can suspend a core commitment device when politics tightens (Department of Finance Canada). All three examples expose the same weakness: without an independent referee, governments can roll carbon budgets forward and spend the option space of later cohorts.

A permanent Carbon Budget Committee can be placed inside each country's public-audit architecture, funded through the ordinary budget yet insulated from ministerial reach. The committee would publish rolling five-year carbon budgets, assign sector ceilings, and issue a March "traffic-light" scorecard. A red light would automatically tighten the next-year cap or raise the auction-reserve floor by a preset increment. Surplus allowances above ten per cent of the cap would cancel automatically, and the committee would approve offset protocols only if they deliver permanent storage and robust monitoring (UNFCCC). By operating under the existing framework climate laws, no new statute is required each cycle, and back-loading becomes procedurally hard.

Turning NDCs into Annual Delivery

Korea leans on offshore credits, Germany moved from sector ceilings to an aggregate target that masks transport slippage, and Canada's price pause weakens broad participation (Climate Action Tracker; Reuters). Ambitious headlines do not translate into yearly action.

Each NDC can be disaggregated into annual economy-wide ceilings and sector pathways through 2035, with a lead ministry carrying a statutory duty to meet its path. Every April, each ministry publishes a one-page compliance statement. If a pathway is missed, a "comply-or-tighten" rule triggers automatically—bringing forward the coal-exit date by one year, lifting the



zero-emission-vehicle quota by five percentage points, or shrinking the free-allocation pool. Ownership is clear and reductions shift into the near term, blocking stealth deferral of effort.

Making Cap-and-Trade Binding

California–Québec’s May 2025 auction cleared the floor, proving that large banks and generous offsets can leave the cap itself non-binding (CARB; S&P Global Commodity Insights). Prices stay above zero but scarcity disappears, letting today’s firms consume the carbon budget meant for later cohorts.

Hard levers that restore scarcity whenever the market slips to the floor would strengthen price credibility. Raise the reserve price automatically when two auctions in a row clear at the floor, publish a dated cap-tightening path to 2035, and cancel any banked volume that exceeds ten per cent of the annual cap. Limit offsets to four per cent of compliance in 2026 and taper to one per cent by 2030 unless the Carbon Budget Committee certifies additionality (ICAP). These steps keep the signal durable across cycles and force abatement inside the cap rather than on paper.

Aligning CBAM with Industry Delivery

The EU’s border price exists in Brussels, yet plant-level investment still depends on firm access to clean power and heat. Free allocation inside the EU ETS blunts the internal cap, and importer-side measurement can lag ETS standards (European Commission).

Border pricing and factory-gate action can be linked through binding roadmaps and transparent revenue recycling. Cement, steel, aluminium, fertiliser, electricity, and hydrogen producers must file roadmaps with 2026, 2030, and 2034 milestones for electrification, low-carbon heat, and fifteen-year clean-power contracts covering at least eighty per cent of energy demand. Public support—grants, contracts for difference, export credit—becomes available only upon signing those contracts. Importers adopt product-level MRV identical to the EU ETS, and no new free allowances issue for CBAM goods after 2026. The Commission publishes the split of CBAM revenue each year, earmarking thirty per cent for partner-country MRV and technology transfer and thirty per cent for domestic just-transition funds. Linking the border rule to plant investment closes the leakage loop without leaving the intergenerational principle stranded at the treaty level.

Conclusion

This study set out to test whether the intergenerational principle—clearly articulated in the Paris Agreement and earlier instruments—has moved from treaty text into the day-to-day machinery of national climate policy. The thesis was that the principle is firmly embedded at the international level but only unevenly at domestication occurring where commitment devices or courts constrain political short-termism.

The five case studies confirm that pattern. The EU’s Carbon Border Adjustment Mechanism carries a long-horizon price signal to the border, yet its full effect still hinges on consistent Member-State enforcement and the planned phase-out of free allowances (European Commission). Germany’s Neubauer judgment secures a legally binding carbon budget, but the 2024 shift from sector ceilings to an aggregate target shows how easily delivery can soften (Climate Case Chart). South Korea’s Constitutional Court has forced year-by-year targets, yet heavy use of overseas reductions and coal in the power mix delays structural change (Climate Action Tracker). Canada’s 2035 NDC aligns with Paris goals, but the 2025 pause of the consumer fuel charge exposes the fragility of price-based commitment devices (Department of Finance Canada). Finally, the California–Québec market keeps a rising reserve price, yet repeated floor-clearing auctions reveal that the cap, not the price floor, is often the non-binding



element (CARB). Together these examples show that international integration is real, while domestic embedding remains contingent.

Critics offer three main counterarguments. Some contend that market-driven innovation will decarbonise the economy without tight legal scaffolding, pointing to rapid cost declines in solar, wind and batteries as evidence that policy need only “nudge” rather than police (Lomborg). Others warn, echoing Okrent, that firm carbon budgets impose disproportionate present-day costs on households and industry and may divert resources from immediate welfare gains (Okrent). A further claim is that automatic correction mechanisms erode democratic accountability by shifting key decisions from elected officials to technocratic bodies, thereby risking a “democratic deficit” in climate governance (Helm).

The evidence reviewed here suggests these objections are overstated. Innovation curves tend to steepen when investors can rely on predictable long-term price signals; independent budget committees make those signals credible without freezing legislative authority. Behavioural studies show that citizens willingly support commitment devices that bind both themselves and their successors because such devices sustain cooperation across generations (Halali and Perez). As for accountability, automatic triggers operate only within parameters that parliament has enacted in advance; legislators retain the authority to amend the framework but cannot quietly defer effort inside a single budget cycle.

The targeted remedies follow directly from those findings. Independent Carbon Budget Committees would lock five-year budgets and trigger automatic corrections when sectors drift off track. Disaggregating every NDC into annual sector pathways, backed by a “comply-or-tighten” rule, would bring headline ambition into the present tense. Cap-and-trade markets can restore scarcity through an indexed reserve-price ratchet, bank-cancellation thresholds and a tapering offset ceiling. CBAM, finally, needs plant-level roadmaps, conditional public finance and transparent revenue recycling to ensure the border price becomes a factory-gate investment signal.

Implementing these measures would narrow the gap between the intergenerational duties declared in Paris and the lived reality of national policy. The principle would no longer rely on scattered court victories or one-off trade rules but would instead be woven into budget cycles, market design and industrial planning. In a world projected to host 9.7 billion people by mid-century while exhausting its 1.5 °C carbon budget within the decade (UN DESA; IPCC), that institutional shift is not a matter of ethical elegance; it is a practical necessity for handing a livable planet to those who come next.

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References

1. Brown Weiss, E. (2008). Climate change, intergenerational equity, and international law. *Vermont Journal of Environmental Law*, 9(3), 615–627.
2. California Air Resources Board. (2025). *Auction notice: California–Québec joint auction of allowances*, 21 May 2025.
3. Climate Action Tracker. (2025). *South Korea*.
4. Climate Case Chart. (2024, May). *Neubauer, et al. v. Germany*.
5. Constitutional Court of Korea. (2024, August 29). *Do-Hyun Kim et al. v. South Korea*.



6. Department of Finance Canada. (2025, March 22). *Removing the consumer carbon price, effective April 1, 2025*.
7. Ember. (2025). *South Korea*.
8. European Commission. (2023, December 13). *Carbon Border Adjustment Mechanism: Questions and answers*.
9. European Parliament. (2023). *Legislative resolution of 18 April 2023 on the proposal for a regulation establishing a Carbon Border Adjustment Mechanism*.
10. European Union. (2023). *Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 establishing a Carbon Border Adjustment Mechanism*. Official Journal of the European Union, L130, 52–104.
11. Halali, E., & Perez, O. (2025). Binding the future boosts intergenerational sustainability. *npj Climate Action*, 4, Article 15.
12. Helm, D. (2020). *Net zero: How we stop causing climate change*. William Collins.
13. International Carbon Action Partnership. (2025). *California cap-and-trade system*.
14. Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report*.
15. Lomborg, B. (2020). *False alarm: How climate change panic costs us trillions, hurts the poor, and fails to fix the planet*. Basic Books.
16. Okrent, D. (1999). On intergenerational equity and its clash with intragenerational equity and on the need for policies to guide regulation of disposal of wastes and other activities posing very long-term risks. *Risk Analysis*, 19(5), 877–901.
17. Pedersen, O. W., & Sulyok, K. (2024). Future generations litigation and transformative changes in environmental governance. *Transnational Environmental Law*, 13(3), 464–474.
18. Reuters. (2024, April 15). German coalition agrees more flexible climate protection law.
19. Reuters. (2025, February 5). Germany likely to miss 2030 climate target, government advisers say.
20. S&P Global Commodity Insights. (2025, May 29). California–Québec carbon auction clears at floor price for first time since 2020.
21. Schuppert, F. (2011). Climate change mitigation and intergenerational justice. *Environmental Politics*, 20(3), 303–321.
22. Slobodian, L. (2020). Defending the future: Intergenerational equity in climate litigation. *Georgetown Environmental Law Review*, 32, 569–589.
23. Spijkers, O. (2018). Intergenerational equity and the Sustainable Development Goals. *Sustainability*, 10(11), Article 3836.
24. United Nations. (1972, June 16). *Declaration of the United Nations Conference on the Human Environment*.
25. United Nations Department of Economic and Social Affairs. (2022). *World population prospects 2022: Summary of results*.
26. United Nations Framework Convention on Climate Change. (1992). *United Nations Framework Convention on Climate Change*.
27. United Nations Framework Convention on Climate Change. (2015, December 12). *Paris Agreement*.
28. United Nations Framework Convention on Climate Change. (2025). *Canada's 2035 national determined contribution*.

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Comprehensive Overview of Penicillin

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Abstract

Penicillin is a β -lactam antibiotic produced by certain *Penicillium* species. It was the first antibiotic found and first mass produced for wide clinical use as a medicine by Alexander Fleming in 1928. Initial preparations of penicillin were unstable, very difficult to purify and not suitable for large scale clinical use. It was the work of Howard Florey, Ernst Chain and others in the late 1930s and early 1940s on the extraction and purification of penic.

Penicillin and its derivatives cause bacterial cell lysis by inhibiting bacterial cell wall synthesis by binding to penicillin-binding proteins. The β -lactam ring is the structure which is responsible for the antibacterial activity as well as the chemical instability of penicillins. As for many other antibioticsase inhibitors led to an extended spectrum of action as well as to an increased resistance to the bacterial β , the development of semisynthetic penicillins as well as of β -lactam and ampicillin, are among the most prescribed antibiotics worldwide and are still of major interest for the β -lactamases. Today, penicillin and its derivatives, e.g. amoxicillin treatment of respiratory tract, skin, urinary tract and also of systemic infections. This review will give an overview on the history of discovery, the structure as well as the biosynthesis of penicillins and on their mechanism of action. Furthermore, it will describe the production of these drugs on an industrial scale, the resistance to penicillins, their pharmacokinetics as well as their clinical application. Finally, an outlook on the current use and future perspectives of penicillins will be given.

In view of the persistence of penicillin and its derivatives (amoxicillin and ampicillin for instance) as among the most widely used antibiotics world-wide, for treatment of most kinds of bacterial infections including respiratory tract infections, of most skin and soft tissue infections, many urinary tract infections, and of systemic (bloodstream) infections, this review provides a fully comprehensive description of all the main aspects, concerning the history of its discovery, the chemical structure of the molecule and of semisynthetic analogs, the biological synthesis of the molecule, the mechanism of action by which the molecule kills bacteria, details of the commercial production of the molecule, reasons for bacterial resistance, pharmacology and clinical use of penicillin and of its many semisynthetic derivatives.

Keywords

Penicillium chrysogenum; β -lactamase; Thiazolidine ring; Ampicillin; Amoxicillin; Fermentation; Clavulanic Acid



Introduction

Penicillin refers to a group of broad-spectrum beta-lactam antibiotics originally derived from and produced by certain species of the fungus *Penicillium*. It was the first antibiotic to be discovered and was the first to be widely used. Its discovery marked a revolution in the field of medicine and has greatly contributed to the field of antibiotic treatment [1].

Penicillin consists of a conserved bicyclic core structure of 6-aminopenicillanic acid that is a highly strained beta-lactam ring fused with a thiazolidine ring, giving antibacterial activity [2]. During the chemical synthesis process of penicillin, it is often cleaved at crucial steps and purified using pH adjustments and crystallization. The beta-lactam ring is covalently attached to the penicillin-binding proteins (PBPs). The PBPs are involved in bacterial cell wall biosynthesis, resulting in cell wall defects and bacterial lysis. The side chain attached to the beta-lactam ring of penicillin allows for modification of penicillin derivatives to improve their stability, spectrum of activity, and pharmacokinetics [3]. Penicillin is used as a medication to treat bacterial infections, such as those caused by susceptible Gram-positive bacteria, and is also used in respiratory, skin, and systemic infections [4].

The discovery of penicillin by Alexander Fleming was reported in 1928. He observed that a *Penicillium* mold culture had an inhibitory effect on the growth of *Staphylococcus* bacteria. The crude product was however, difficult to purify and to stabilize. The crude penicillin preparations were very chemically heterogeneous and unstable, no matter what the storage conditions, and they were not always suitable for therapeutic use in man or animals.

In the 1930s, the molecular structure of penicillin was not well understood, and various proposed structures were based on its behavior in the laboratory. Many models were proposed, such as a peptide structure as well as a variety of cyclic thioether structures. None of the proposed models could adequately explain the instability of penicillin under certain conditions nor fully utilize the antibacterial potential of the molecule. Consequently, the true structure of penicillin was not determined, and derivatives that could more fully utilize the activity of the molecule were not developed [5].

The discovery of penicillin's structure in the late 1930s and early 1940s was made possible by Florey, Chain, and others' improvement of methods for culturing, extracting, and purifying penicillin to the point where they could obtain clinically useful amounts of a pure and stable form of penicillin. This, together with improvements in the fermentation and chemical processes during WWII, allowed the large-scale production of penicillin, making it available as a routine clinical medication. Further work on the beta-lactam ring allowed derived structures of the natural penicillins as well as synthetic penicillins to be synthesised, which provided more stable analogues with broader spectra of activity and better resistance to degradation by bacterial beta-lactamases. Penicillin quickly became a base compound from which many synthetic derivatives could be developed leading to a revolution in the field of antibiotic research [6].

Summary and Impact Penicillin Discovery, Structure, and Pharmacology: Past, Present and Future Penicillin has played a significant role in the field of antibiotic science, as the first and by all means, the most successful antimicrobial drug. This review deals with every aspect of penicillin including its discovery and history, its structure, biosynthesis, modes of action, total synthesis and manufacture, pharmacokinetics and metabolism, as well as second-generation semisynthetic derivatives and their analogs. The present work provides a completely integrated view of penicillin and its role in antibiotic science, highlighting its continued and lasting impact as a paradigm in the field of antibiotics and illustrating how penicillin can serve as a benchmark for the design and development of new drugs and thereby contribute to the future of antimicrobial therapeutics.



Despite the development of newer antimicrobial agents, penicillin and its semisynthetic derivatives continue to remain essential components of modern clinical practice. Antibiotics such as amoxicillin and ampicillin are still widely prescribed for respiratory tract infections, skin infections, urinary tract infections, and bacterial pneumonia. However, the increasing emergence of antimicrobial resistance and β -lactamase-producing bacteria has also driven continued research into modified penicillin derivatives and β -lactamase inhibitors. Therefore, penicillin remains both a historical breakthrough and an ongoing subject of pharmaceutical and clinical research.

Methods

A literature review was conducted using Google Scholar, PubMed, and the National Institutes of Health (NIH) to examine the biological significance, synthesis, fermentation, and pharmaceutical relevance of penicillin and related β -lactam antibiotics. Initial searches focused on " β -lactamase", "Thiazolidine ring" to evaluate structural knowledge of penicillin. The specific type of penicillin was then narrowed using keywords such as "ampicillin" and "Amoxicillin". Further searches included "Fermentation" and "Clavulanic Acid" for an understanding of natural penicillin production and β -lactamase inhibitors. Peer-reviewed articles were selected to support the analysis of enzymatic pathways, chemical mechanisms, modification, and clinical relevance.

Results and Discussion

1. Biological and medicinal significance and activity

1.1. Structure of beta-lactam

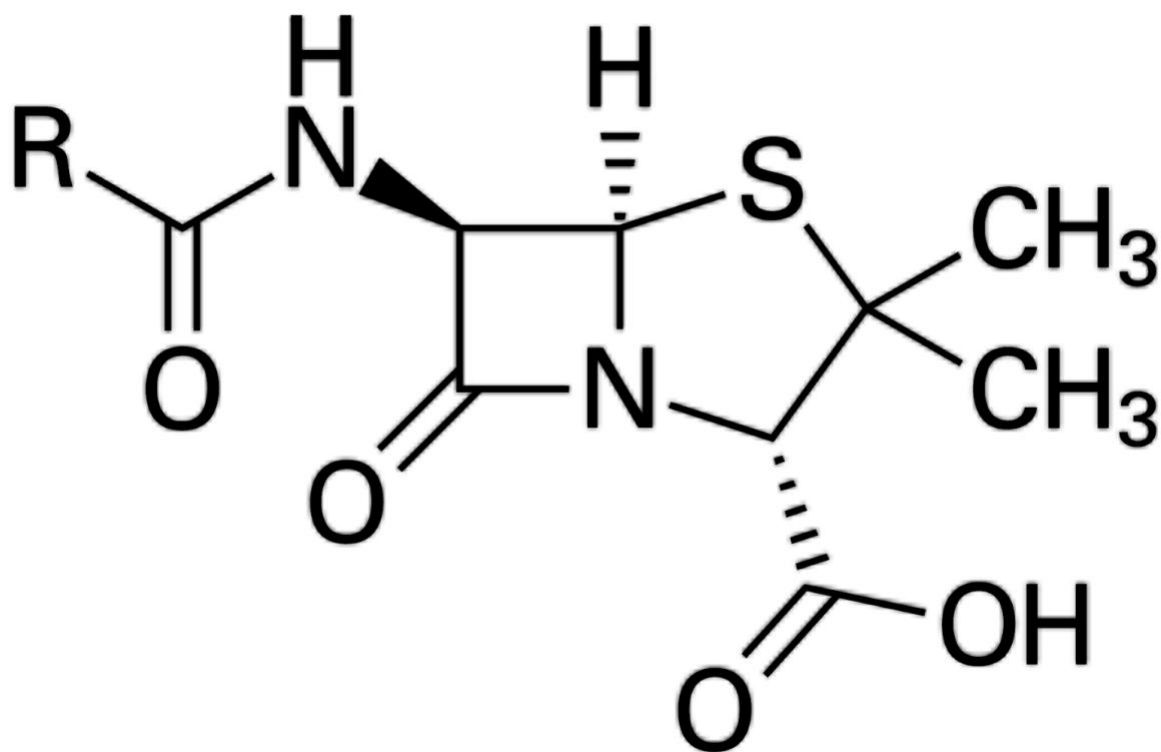


Figure 1. Structure of penicillin



β -lactam antibiotics are a class of antibiotics that are used in clinical practice in both oral and parenteral forms [7]. The β -lactam ring is a core chemical structure of a four-membered ring found in major classes of antibiotics that fight bacterial infection by inhibiting bacterial cell wall synthesis, making them bactericidal. The carbon on the β -lactam ring connected to an amine group has sp^3 hybridization, which normally has a bond angle of 109.5 degrees. However, due to the rectangular four-membered ring, the bond angle has been restricted to 90 degrees, as shown in the figure above. The angle strain raises the energy and weakens the bonds, making the molecule very reactive.

1.2 Biological significance and activity

Paul Ehrlich, a German physician established the theory of selective toxicity which is the fundamental principle that makes the antibacterial agents work. Paul has defined antibacterial agents as “substances with an exclusive affinity for bacteria acting deleteriously or lethally on these alone, while at the same time, they possess no affinity for the normal constituents of the body...”. The selective toxicity of β -lactams, for example, is considered to be due to their affinity to penicillin-binding proteins (PBPs) and inhibition of biosynthesis of bacterial cell walls [8]. Penicillin has the unique ability to target the synthesis of peptidoglycan which is a complex polymer that forms the rigid bacterial cell wall. As penicillin inhibits the PBP that builds the essential bacterial component, it leads to cell lysis from osmotic pressure acting as a bactericidal. However, the fact that human cells are not made up of peptidoglycan makes penicillin deadly to bacteria while generally safe for the human body.

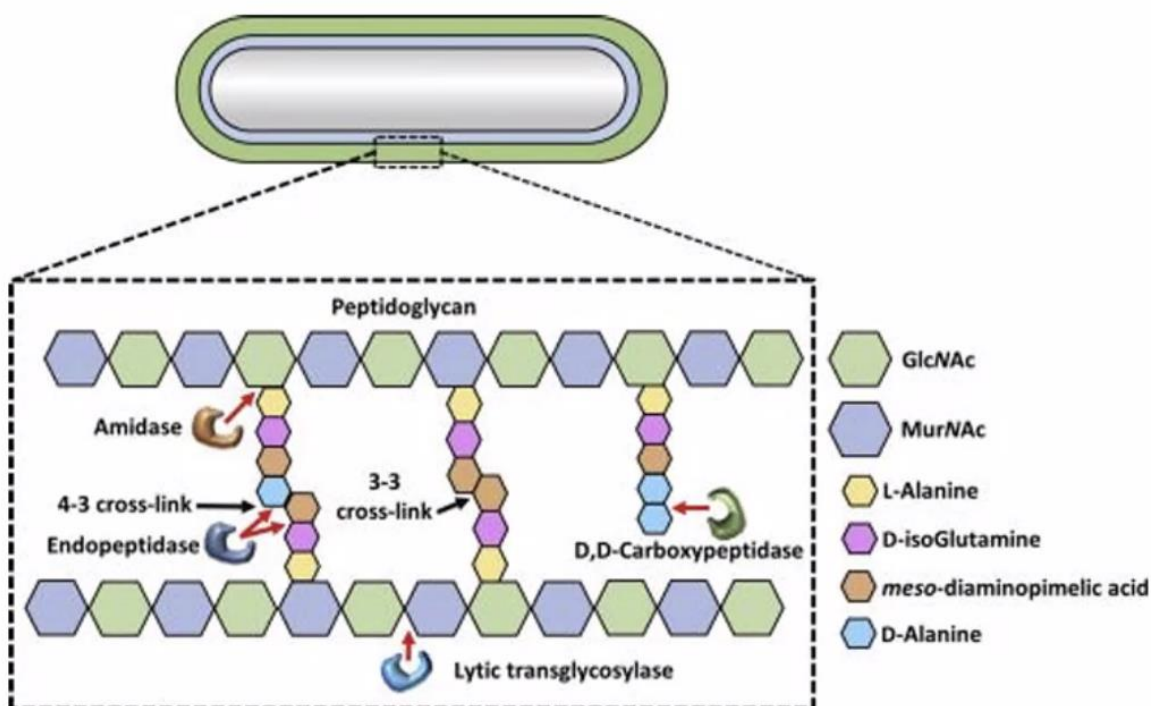


Figure 2. Biological context of penicillin actions

In making and maintaining the cell wall, bacteria have this polymer peptidoglycan which is composed of carbohydrates and short chains of amino acids. The catalyst for this reaction is PBP such as the enzyme DD-transpeptidase which carries out the cross-linking of the cell wall as well as the trimming of



peptidoglycan. The penicillin's beta-lactam ring binds to DD-transpeptidase to irreversibly inactivate cell wall synthesis of bacteria.

1.3 Medicinal significance and activity

After its discovery in 1928, penicillin has been widely used across the world in the field of medicine as the first true antibiotic. The discovery and development of penicillin marked a turning point in the medical field, facilitating the treatment of lethal infections into treatable diseases. Penicillin is mostly used with the treatment of pneumonia, syphilis and meningitis commonly caused by bacteria where penicillin is used to inhibit the synthesis of the bacterial cell wall ultimately killing the bacteria that cause these infections.

Furthermore, penicillin controlled the infections, enabling modern surgery, cancer chemotherapy, and organ transplantation. Before the discovery of penicillin, even clean operations often led to deadly postoperative infections. However, now, with the use of penicillin, it prevents and treats surgical site infections, specifically common bacteria like *Staphylococcus* and *Streptococcus*. The effectiveness and safety of the use of penicillin has been significant in medical value. Penicillin has a high therapeutic index, meaning that the toxic dose is much higher than the effective dose. It further implies that a drug has a wide margin of safety between the dose that produces a therapeutic effect and the dose that causes toxicity, making it relatively safe for clinical use. Therefore, with a low dose, penicillin is effective and well-tolerated. Moreover, with the widespread use of penicillin, it is inexpensive and affordable, which remains relatively inexpensive compared with many newer antibiotics [9].

Taking in consideration of current clinical guidelines, penicillin and its derivatives are the first-line treatments for multiple bacterial infections. For example, natural penicillins of penicillin G and V are still recommended by various guidelines such as the Infectious Diseases Society of America known as IDSA for treating streptococcal pharyngitis, syphilis, and pneumonia mainly caused by *Streptococcal pneumoniae*. More derivatives of penicillin includes amoxicillin and ampicillin which are currently recommended for conditions like otitis media, urinary infections, and others caused by both gram-positive and negative bacteria. They are prescribed to minimize resistance development but also cure infections from bacteria quickly within a short period of time.

2. Biological mechanism of action

2.1 Role of penicillin as a mechanism based inhibitor

Mechanism-based inhibition is a type of inhibition where a competitive inhibitor irreversibly binds to the active site, to permanently inactivate the enzyme. This happens when the beta-lactam ring is opened and becomes activated, forming a covalent bond with the threonine amino acids located in the active site of the transpeptidase enzyme. The binding is irreversible and permanently disallows the transpeptidase enzyme from functioning. The permanent inactivation of transpeptidase leads to cell lysis under osmotic pressure. As the transpeptidase is inactivated, the enzymes that create new layers of peptidoglycan are inactivated while enzymes that break down old layers continue to function. Therefore, continuous breakdown of the old peptidoglycan layer while inhibition of cell wall synthesis causes the cell wall to become thinner which results in cell lysis when water is taken up.



2.2 Process by which bacteria become resistant to penicillin

2.2.1 Base substitution mutation

		2 nd Base					
		U	C	A	G		
1 st Base	U	UUU Phenylalanine UUC Phenylalanine UUA Leucine UUG Leucine	UCU Serine UCC Serine UCA Serine UCG Serine	UAU Tyrosine UAC Tyrosine UAA Stop UAG Stop	UGU Cysteine UGC Cysteine UGA Stop UGG Tryptophan	U C A G	3 rd Base
	C	CUU Leucine CUC Leucine CUA Leucine CUG Leucine	CCU Proline CCC Proline CCA Proline CCG Proline	CAU Histidine CAC Histidine CAA Glutamine CAG Glutamine	CGU Arginine CGC Arginine CGA Arginine CGG Arginine	U C A G	
	A	AUU Isoleucine AUC Isoleucine AUA Isoleucine AUG Methionine (Start)	ACU Threonine ACC Threonine ACA Threonine ACG Threonine	AAU Asparagine AAC Asparagine AAA Lysine AAG Lysine	AGU Serine AGC Serine AGA Arginine AGG Arginine	U C A G	
	G	GUU Valine GUC Valine GUA Valine GUG Valine	GCU Alanine GCC Alanine GCA Alanine GCG Alanine	GAU Aspartic Acid GAC Aspartic Acid GAA Glutamic Acid GAG Glutamic Acid	GGU Glycine GGC Glycine GGA Glycine GGG Glycine	U C A G	
		Nonpolar, aliphatic	Polar, uncharged	Aromatic	Positively charged	Negatively charged	

Figure 3. Genetic code and RNA Codon Table

One process by which bacteria become resistant to penicillin is by base substitution mutation, a natural process that happens randomly and spontaneously. The base substitution mutation involves change in a particular base to another base therefore, leading to the production of a different codon in the bacterial mRNA. This mutation occurs in the gene that codes for the bacterial enzyme transpeptidase. The codon which originally coded for threonine, is mutated into a different codon that codes for serine. The threonine amino acids in the active site of transpeptidase are replaced by serine where penicillin are no longer able to bind to the active site due to conformational change of the active site.

2.2.2. β -lactamase acylation mechanism

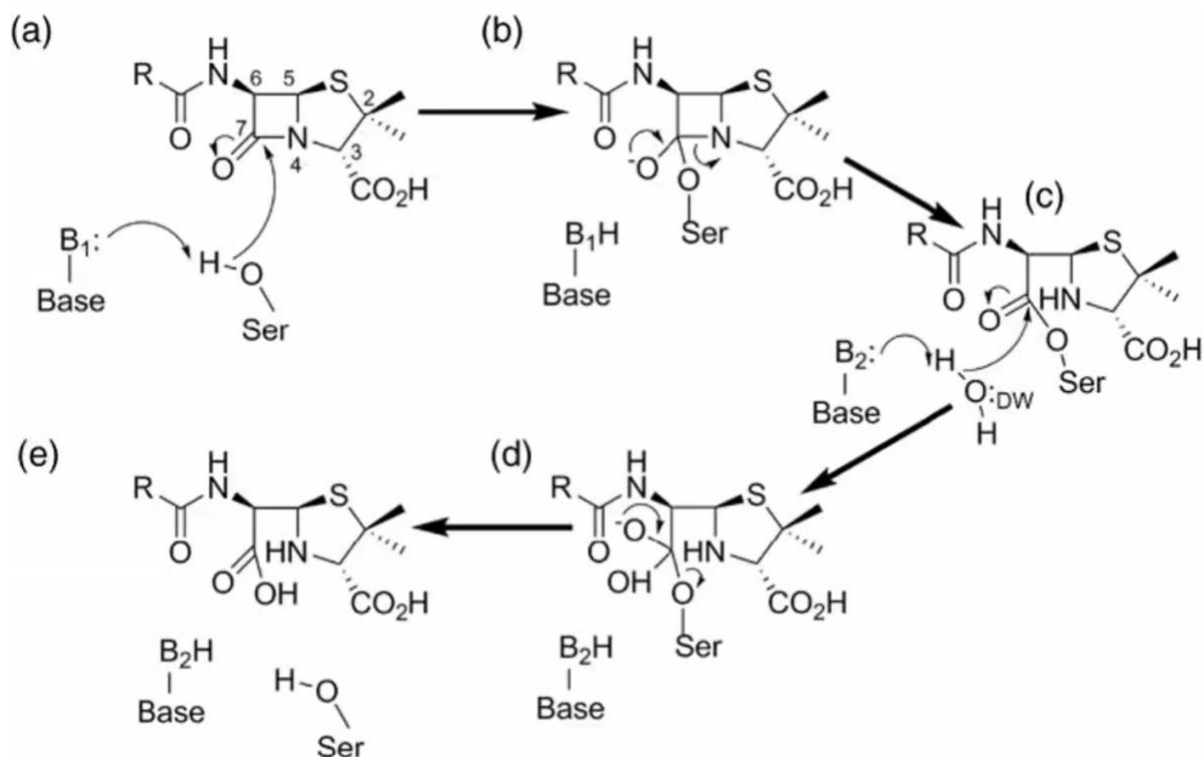


Figure 4. Mechanism overview of serine β -lactamase

Another process by which bacteria become resistant to penicillin is β -lactamase acylation. β -lactamase is a bacterial enzyme that inactivates β -lactam antibiotics, both produced by gram-positive and gram-negative bacteria by breaking the core chemical structure of the β -lactam ring.

Figure 4. shows the hydrolysis of generic penicillin substrate due to serine β -lactamase. (a) General base B1 activates Ser for nucleophilic attack on the amide carbonyl carbon (C7) generating covalent acyl-enzyme (c) via tetrahedral oxyanionic acylation transition state (b). General base B2 activates incoming deacylating water molecule (DW) for nucleophilic attack on the acyl-enzyme carbonyl liberating penicilloate product (e) via tetrahedral deacylation transition state (d). [10]

Overall, there are two major reactions involved: acylation and hydrolysis. In the acylation reaction, the serine β -lactamase nucleophilic serine residue attacks the substrate β -lactam ring of the penicillin, yielding an ester-linked acyl-enzyme complex. In the hydrolysis reaction, the nucleophilic attack of a water molecule onto the acyl-enzyme complex carbonyl occurs, hydrolysing the antibiotic and releasing the serine.

Therefore, bacteria can become resistant to penicillin by a natural process of base substitutional mutation or through the production of serine β -lactamase. The base substitution mutation involves mutation of the codon that codes for threonine to serine restricting from the binding to the active site. While a mechanism involving serine β -lactamase inactivates the antibiotic via acylation followed by hydrolysis reactions.

3. Biological mechanism & clinical use



3.1 Biological synthesis

Natural penicillins are β -lactam antibiotics biosynthesized by fermenting the fungus *Penicillium chrysogenum*, which includes Benzylpenicillin (Penicillin G) and Phenoxymethylpenicillin (Penicillin V). The specific type of natural penicillin production is determined by the precursor added to the fermentation medium, where phenylacetic acid yields Benzylpenicillin (penicillin G), and phenoxyacetic acid yields Phenoxymethylpenicillin (Penicillin V) [11].

The process starts with the precursors in the cytosol, which are three amino acids: L- α -aminoadipic acid (L- α -AAA), L-cysteine, and L-valine. These amino acids are condensed into a tripeptide δ -(L- α -aminoadipyl)-L-cysteinyl-D-valine (LLD-ACV) by a nonribosomal peptide synthetase (NRPS) δ -(L- α -aminoadipyl)-L-cysteinyl-D-valine synthetase (ACVS) that catalyzes the formation of a linear tripeptide, which is encoded by *pcbAB* [12,13,14,15]. The tripeptide LLD-ACV is oxidized into isopenicillin N by the enzyme isopenicillin N synthase (INPS), which is encoded by *pcbC* [13,16]. All penicillins have a bicyclic ring structure, a four-membered β -lactam ring linked to a five-membered thiazolidine ring, which is formed when the tripeptide precursor undergoes oxidative ring closure.

Here, the amide functional group and sulfhydryl group lose hydrogen and form a part of the penicillin core, forming the β -lactam ring, which is responsible for penicillin's antibacterial activity. Finally, the side chain of isopenicillin N, which is α -aminoadipyl, is replaced with a new side chain by phenoxyacetyl-CoA, catalyzed by isopenicillin N acyltransferase (IAT), encoded by *penDE* [17,18,19,20]. The formation of the side chain phenylacetyl group produces penicillin G, and the side chain phenoxyacetyl group, benzene ring with oxygen atom, produces penicillin V [21].

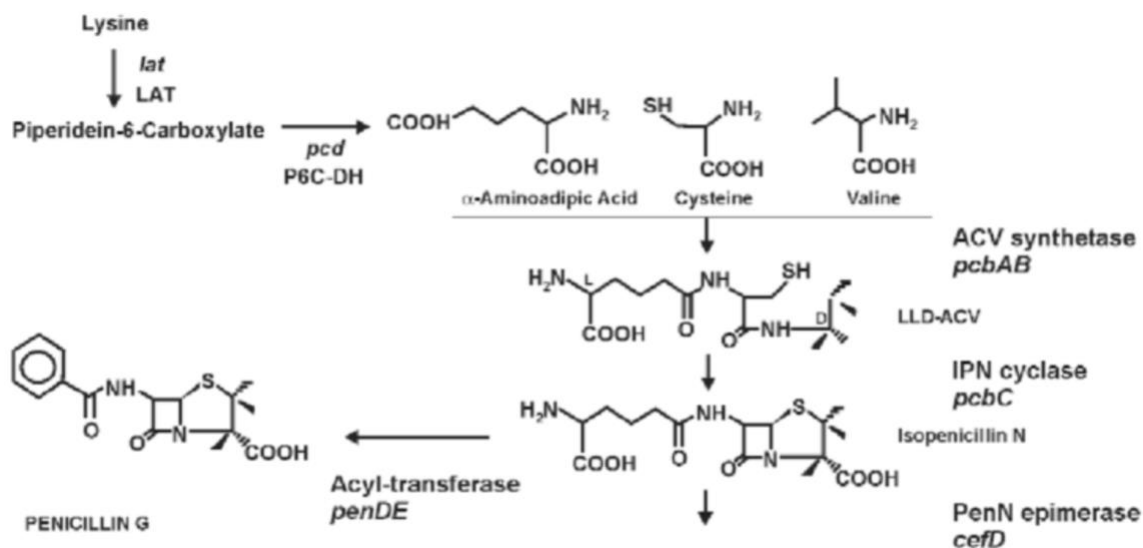


Figure 5. Biosynthetic pathway of penicillin in *Penicillium chrysogenum* [22]

Lysine is converted to α -aminoadipic acid, combining with cysteine and valine to form ACV tripeptide through ACV synthetase. The tripeptide forms the β -lactam core of penicillin, followed by side-chain replacement to produce penicillin G.



3.2 Active pharmaceutical ingredient (API)

The production of penicillin on the Active Pharmaceutical ingredient(API) involves complex fermentation and chemical purification. The typical stages in the production of API are fermentation, recovery, extraction, purification, crystallization, and quality control.

For the mass production of penicillin, fermentation takes place in stainless steel tank reactors that have a capacity of 30 to 100 thousand gallons. To increase the yield of the *Penicillium chrysogenum* strain, improvements in the medium composition, large industrial tanks, and sterile air are necessary. In current commercial manufacturing, strains of *Penicillium chrysogenum* are cultivated in continuously agitated 50,000-gallon stainless steel tanks by submerged fermentation, which results in 40-50 grams of penicillin per liter of culture with recovery yields up to 90% [24]. Recovery and extraction are needed for higher yield and stability. Historically, penicillin recovery relied heavily on conventional solvent extraction using organic solvents such as n-butyl acetate and amyl acetate [25,26]. Although effective, these methods required high solvent consumption and multiple extraction steps [25,26]. However, there are several drawbacks to utilizing conventional solvent extraction, which include high solvent consumption, the need for multiple extraction steps, lower yields, and a risk of emulsification [27]. Many other alternative extraction methods emerged. To address these limitations, researchers later proposed alternative recovery techniques. For example, Edmundowicz et al. developed a non-extractive recovery method. It resulted in an overall yield of approximately 56% by acidifying the fermentation broth without organic solvent extraction [28]. Furthermore, a water-oil emulsion that uses di-n-octylamine as a carrier, a liquid surfactant membrane method from Hano et al., allowed the prompt recovery of penicillin G; however, it had a drawback that required low membrane stability and organic solvents [27]. Adsorption using hydrophobic resins by de Barros et al. recovered penicillin G. This method provided insights for adsorption-based recovery techniques; however, it faced difficulty in maintaining low temperatures as well as acidic pH levels, which are essential requirements for stability [29]. Following extraction, penicillin is then converted into a salt by separating the penicillin from culture liquors, which creates a concentrated but impure water solution. This step is essential as it reduces the volume by isolating the active penicillin ingredient from a large amount of fermentation broth. Penicillin is combined with sodium and potassium, forming a penicillin salt concentrate. Water is removed by distillation, leaving the organic solvent [28].

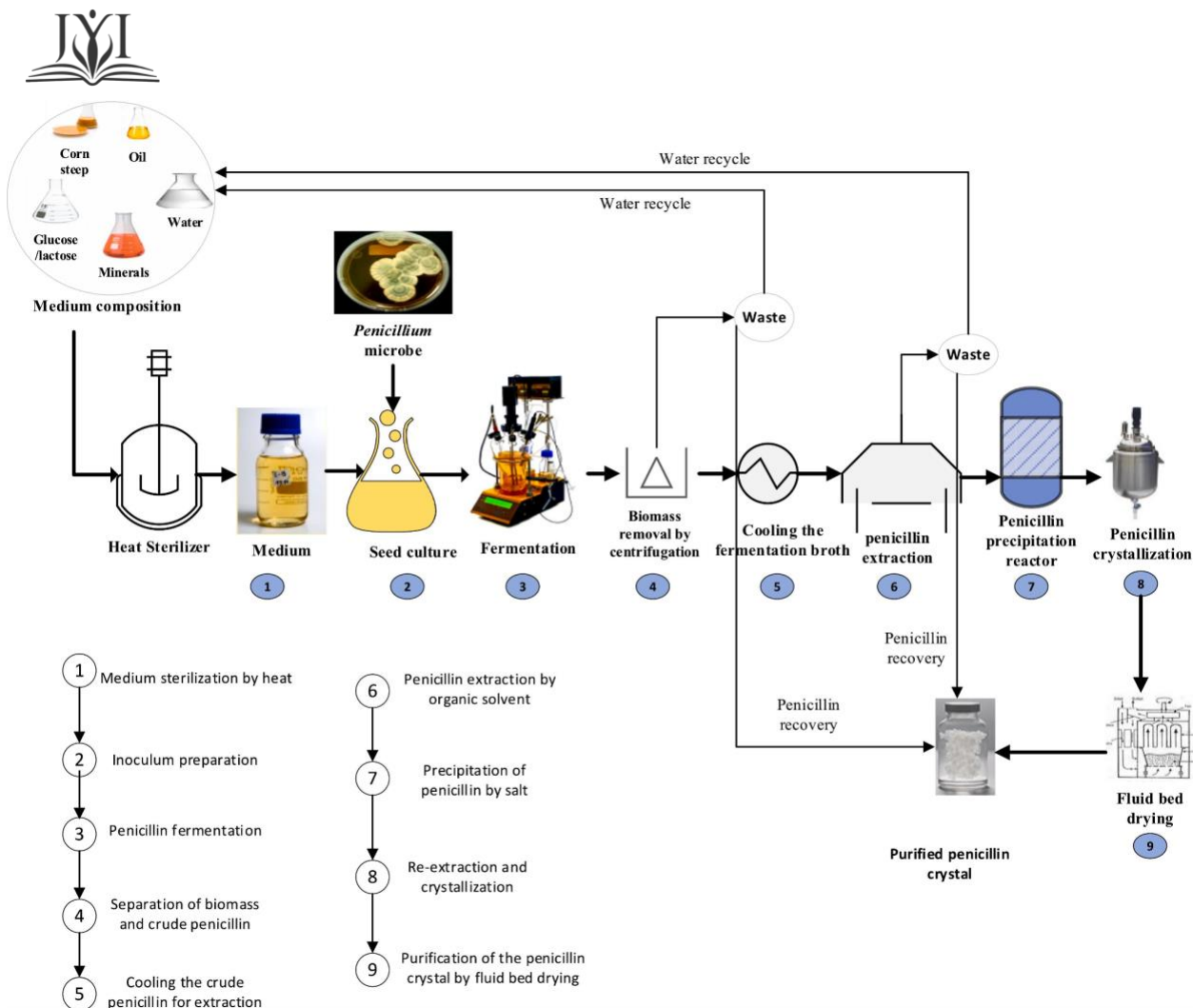


Figure 6. Overview of the current industrial penicillin API production process

API production starts with preparation and heat sterilization of the nutrient medium, with inoculum development and large-scale fermentation using the *Penicillium* species. After fermentation, biomass is removed by centrifugation and cooled. It is then extracted using an organic solvent and re-extracted for purification. The final steps include crystallization and drying of purified penicillin crystals [25].

Finally, the API is required to undergo quality controls confirmed by Good Manufacturing Practice(GMP). GMP affirms that medical products are appropriately used and controlled to the standards [28] The GMP for each country varies, including the United States' Food and Drug Administration(FDA), European Medicines Agency(EMA) for Europe, China Food and Drug Administration(CFDA) for China, and the World Health Organization(WHO), which sets international standards for pharmaceutical products. As penicillin has a strong allergenic potential, current GMP requirements require that it be produced in a fully separate facility to avoid contamination. Further quality control also includes impurity profiling, potency testing, and stability sampling over time [30].

4. Chemical synthesis

The first total synthesis by John Sheehan in 1957 confirmed penicillin's molecular structure and the possibility of it being produced independently of biological systems. It required the synthesis of the highly strained β -lactam ring and fused thiazolidine ring. This was a 5-step chemical synthesis involving the formation of the thiazolidine ring through condensation, deprotection of the amine, acylation of the side chain, deprotection of the carboxylic acid, and closure of the β -lactam ring [31,32,33,34]. Although Sheehan succeeded in penicillin's total synthesis, it resulted in an overall yield of about 0.7% [34]. This inefficiency prevented total synthesis from being used for industrial production. Still, the total synthesis laid its importance in advancing the field of β -lactam antibiotics by confirming its structure. Furthermore, the modern production of penicillin was achieved through fermentation, followed by semi-synthetic modification to create different penicillin derivatives. For this process, natural penicillin serves as a starting material and is then converted into a core intermediate 6-aminopenicillanic acid that removes the original side chain while retaining the original 6-APA structure [35,36]. Different acyl side chains can then be attached to create new antibiotics, modifying properties such as acid stability, oral bioavailability, and resistance to bacterial enzymes [37].

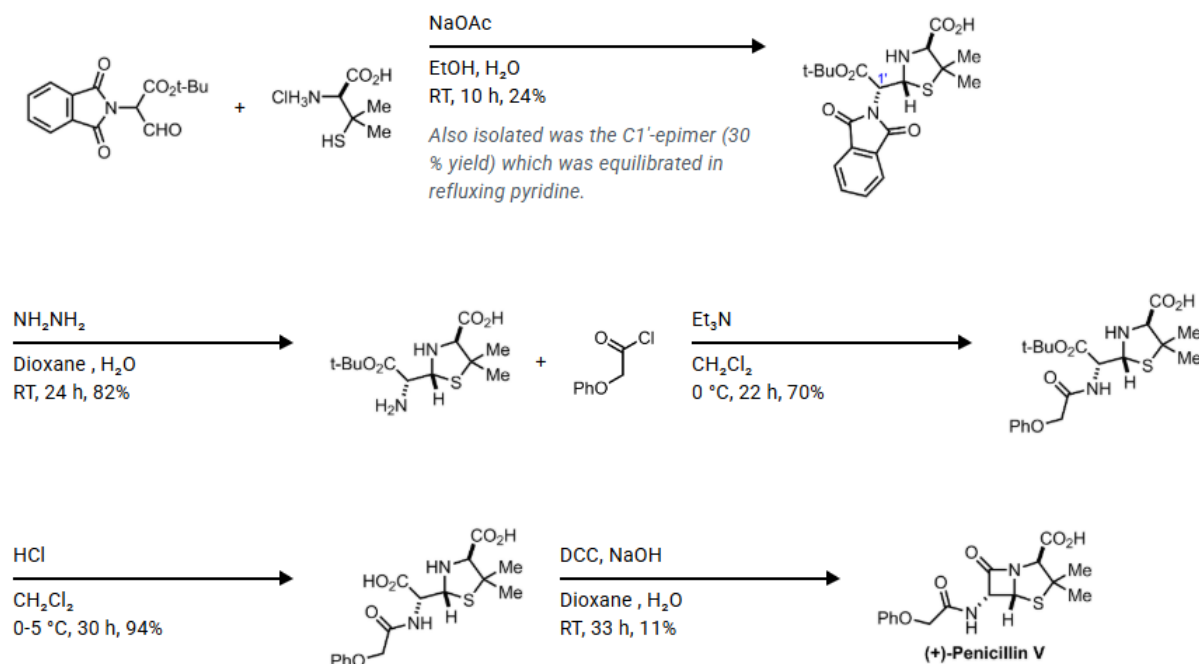


Figure 7. The 5 linear steps to John Sheehan's total synthesis [31]

5. Pharmacokinetics of selected penicillin drugs

When administered orally, Benzylpenicillin demonstrates low bioavailability (<30%) due to degradation by gastric acid. Thus, intravenous or intramuscular administration is the preferred route [38]. Benzylpenicillin gets distributed extensively throughout tissues and body fluids [39]. Benzylpenicillin had an elimination half-life of 0.54 hours when administered intravenously [40]. Approximately 40% of Benzylpenicillin is metabolized in the liver, with penicilloic acid as the primary metabolite. Renal excretion accounts for between 60%–90% of the elimination process [41].

Phenoxymethylpenicillin displays an oral bioavailability of 60%–70%, a huge surge from that of benzylpenicillin, due to its greater acid stability [38]. Following oral administration, phenoxymethylpenicillin shows extensive distribution into tissues and body fluids, like benzylpenicillin [39]. The elimination half-life ranges from 0.5 to 0.8 hours [41]. Its hepatic metabolism is limited, with penicilloic acid as the main metabolite, and renal clearance remains the main route for elimination [42,43].

Oral administration of Ampicillin leads to moderate absorption with a bioavailability of 30-55% [39]. Then, upon administration, ampicillin is broadly distributed in most tissues, body fluids, and organs. The elimination half-life of the drug is approximately 1.33 hours [46]. Its hepatic metabolism is limited to just 20% of a 250-500mg dose to healthy adults [45]. Elimination through the renal system via glomerular filtration and tubular secretion takes place in 12 hours following dosing of a small fraction of a dose (7%) [46,47].

Following oral administration, amoxicillin demonstrates a bioavailability of approximately 95%. The elimination half-life in adults ranges from 1 to 1.5 hours, and the drug shows extensive distribution into tissues and body fluids [48]. Amoxicillin undergoes hepatic metabolism through oxidation, hydroxylation, and deamination pathways [49]. Renal excretion is the predominant elimination route, with 60-70% of an orally administered dose excreted unchanged in the urine within 6-8 hours [50].

5. 1 Second and further generation variants of penicillin

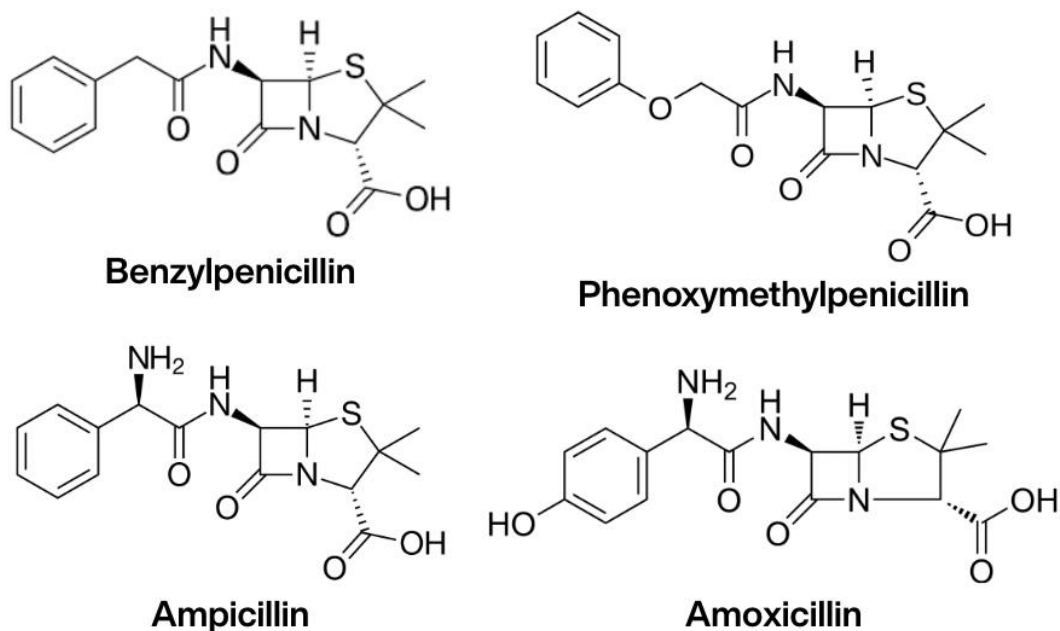


Figure. 8. Structures of common penicillin antibiotics



The development of the second-generation and later penicillin variants emerged as a result of semi-synthesis, driven by the need to overcome the limitations of natural penicillin, including a narrow antibacterial spectrum, poor oral bioavailability, and vulnerability to β -lactamase enzymes. Many of these derivatives still remain widely used in modern clinical practice and are frequently recommended in current treatment guidelines for bacterial infections.

Classified as aminopenicillins, second-generation variants such as ampicillin and amoxicillin are semisynthetic compounds derived from the penicillin parent. The primary structural distinction of ampicillin and amoxicillin (Figure 8) from other penicillins is the presence of an amino group attached to the β -lactam side chain. This amino group substitution was specifically designed to enhance penetration through the outer membrane of Gram-negative bacteria. Consequently, this structural modification broadened the antimicrobial spectrum beyond the predominantly Gram-positive coverage of earlier penicillins to include clinically important Gram-negative pathogens such as *Haemophilus influenzae*, *Escherichia coli*, and *Proteus mirabilis* [51].

Today, amoxicillin remains one of the most commonly prescribed antibiotics worldwide and is currently recommended as treatment for conditions such as tonsillitis, respiratory tract infections caused by *Streptococcus* species, and community-acquired pneumonia. Ampicillin continues to be used in hospital settings for infections, including bacterial meningitis, genitourinary infections, and septicemia. These derivatives are valued in current clinical practice because of their broad antibacterial spectrum, relatively low toxicity, and effectiveness against susceptible bacterial species.

Particularly, Amoxicillin was structurally modified to enhance oral bioavailability. It works as an amphoteric compound and has a distinctive side chain with a protonated amino group (pKa 2.63) that has strong electron-withdrawing characteristics, making it more acid-resistant than penicillin G [52]. This improved acid stability allows amoxicillin to be administered orally with high absorption, making it commonly used as an oral antibiotic today.

Co-administration of β -lactamase inhibitors with penicillins protects the core structure that gives penicillins their antibacterial activity by preventing β -lactamase enzymes from hydrolyzing the β -lactam ring. In current clinical settings, combinations such as amoxicillin–clavulanic acid and ampicillin–sulbactam are frequently prescribed to treat infections caused by β -lactamase-producing bacteria, including respiratory tract infections and gastrointestinal infections. Typically, these inhibitors are combined as separate substances within the same dosage form during the pharmaceutical formulation process rather than being covalently bound to the penicillin molecule. Sultamicillin, a medication created by chemically bonding ampicillin with the β -lactamase inhibitor sulbactam, is a notable exception.

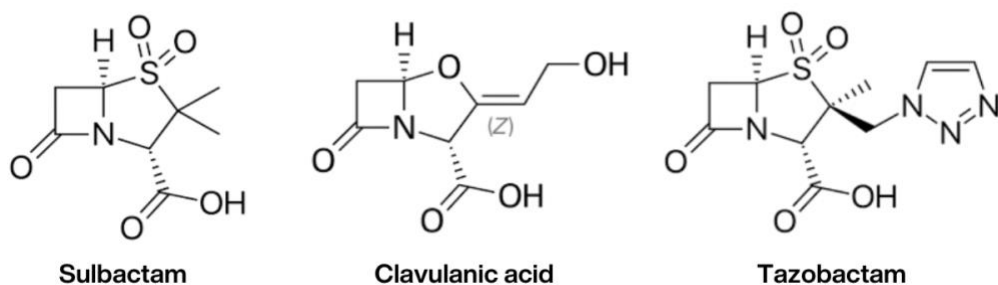


Figure. 9. Structures of β -lactamase Inhibitors



When an enzyme and an inhibitor interact, three different pathways could lead to the formation of a covalent acyl-enzyme intermediate. One approach involves developing a state of a temporarily inactivated enzyme, which deactivates catalytic activity without causing irreversible structural damage. This is similar to reversible inhibition mechanisms, which allow the recovery of enzymatic activity in response to changed environmental conditions.

Alternatively, the acyl-enzyme intermediate might resemble conventional interactions between enzymes and substrates. This process releases the breakdown product and regenerates the unbound, active enzyme by hydrolyzing the inhibitor clavulanic acid. A third possibility is complete and irreversible deactivation of the enzyme, in which the acyl-enzyme complex becomes an irreversibly inactivated species. This pathway is the most clinically desirable outcome for antimicrobial agents, as it achieves suppression of bacterial enzyme function, thereby potentiating antibiotic efficacy [53].

Sulbactam and clavulanic acid had similar inhibitory profiles, meaning they blocked the same types of enzymes to a comparable extent. Both drugs were less effective at inhibiting cephalosporinases, which are beta-lactamases that primarily destroy cephalosporins (a type of beta-lactam antibiotic), than they were at inhibiting penicillinases or broad-spectrum beta-lactamases, which can inactivate many different beta-lactam antibiotics. However, the difference in effectiveness between these enzyme classes was smaller for sulbactam, because sulbactam showed slightly better activity against cephalosporinases than clavulanic acid. Sulbactam and tazobactam both follow the same inhibitory pathway as clavulanic acid [53].



Figure 10. Structures of Second-Generation Variants of Penicillin

An alternative strategy for protecting the β -lactam ring from enzymatic degradation involves steric hindrance through structural modifications. By incorporating bulky substituents adjacent to the β -lactam moiety, these penicillin derivatives create spatial constraints that physically prevent β -lactamase enzyme access to the reactive carbonyl group within the ring. This three-dimensional shielding effect generates an energetically and geometrically unfavorable environment for the enzyme to properly orient and execute nucleophilic attack on the β -lactam bond. Therefore, sterically hindered penicillins maintain their antibacterial activity without the need for co-administration of separate β -lactamase inhibitors, even in the presence of β -lactamase-producing bacteria [53].

Conclusion

Penicillin serves as one of the most transformative discoveries in the history of medicine and the pharmaceutical field until nowadays. Marking the beginning of the discovery by Alexander Fleming to the



enlarged industrial production stage, especially during the World War 2 era, penicillin played and continues to play a crucial role in our society all over the world. The introduction of penicillin has saved thousands and millions of people from infectious diseases that were once untreatable to advancing procedure of surgery and organ transplantation in a safer way.

At a molecular level, penicillin is widely used in medical practices due to its high effectiveness just with the usage of low doses relative to other antibiotics. The β -lactam structure of penicillin plays a significant role in other antibacterial activity and its vulnerability to resistance mechanisms. By inhibiting penicillin-binding proteins (PBPs) and disrupting the building blocks of cell wall (peptidoglycan) at the same time, penicillin specifically targets bacteria with its property of high selective toxicity and high therapeutic index, which allows relatively low doses to be used with the same effectiveness as others.

The further advancement in biosynthesis, fermentation technology, and active pharmaceutical production presents a wide range of usage not only in the medical field but also more. The evolution from natural penicillin G and V to semi-synthetic and finally to second-generation derivations, including ampicillin and amoxicillin stretches and expands the spectrum of activities as antibacterial.

Despite the continuous emergence of other antibiotics from scientists all over the world, penicillin still serves as a historical breakthrough and ongoing innovation with expanding its importance from the fields of Biology, Chemistry, and primarily in the pharmaceutical field against infectious diseases.

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References

- [1] Aminov, R. I. (2020). A brief history of the antibiotic era: Lessons learned and challenges for the future. *Frontiers in Microbiology*, 11, 590. <https://doi.org/10.3389/fmicb.2020.00590>
- [2] Pharmacy Concepts. (2022). *Penicillin*. <https://pharmacyconcepts.in/wp-content/uploads/2022/01/Penicillin.pdf>
- [3] Bush, K., & Bradford, P. A. (2023). β -Lactams and β -lactamase inhibitors: An overview. *Cold Spring Harbor Perspectives in Medicine*, 13(5), a025247. <https://doi.org/10.1101/cshperspect.a025247>
- [4] Katzung, B. G., & Trevor, A. J. (2021). *Basic and clinical pharmacology* (15th ed.). McGraw Hill Education. <https://accessmedicine.mhmedical.com/book.aspx?bookID=2988>
- [5] Hutchings, M. I., Truman, A. W., & Wilkinson, B. (2019). Antibiotics: Past, present and future. *Current Opinion in Microbiology*, 51, 72–80.
- [6] Ligon, B. L. (2004). Penicillin: Its discovery and early development. *Seminars in Pediatric Infectious Diseases*, 15(1), 52 to 57. <https://doi.org/10.1053/j.spid.2004.02.001>
- [7] Abbas, Ali Taher, et al. "Review of Beta Lactams." Review-of-Beta-Lactams, vol. 26, no. 1, Jan. 2022, pp. 1863–81, www.researchgate.net/publication/364720286_Review_of_Beta_lactams.
- [8] ---. "Selective Toxicity of Antibacterial Agents—Still a Valid Concept or Do We Miss Chances and Ignore Risks?" *Infection*, vol. 49, no. 1, Dec. 2020, pp. 29–56, <https://doi.org/10.1007/s15010-020-01536-y>.
- [9] Powell, N., et al. "Impact of Penicillin Allergy Records on Antibiotic Costs and Length of Hospital Stay: A Single-Centre Observational Retrospective Cohort." *Journal of Hospital Infection*, vol. 106, no. 1, Sept. 2020, pp. 35–42, <https://doi.org/10.1016/j.jhin.2020.05.042>. Accessed 30 Aug. 2020.
- [10] " β -Lactamases and β -Lactamase Inhibitors in the 21st Century." *Journal of Molecular Biology*, vol. 431, no. 18, Aug. 2019, pp. 3472–500, <https://doi.org/10.1016/j.jmb.2019.04.002>.
- [11] Ball AP, Gray JA, Murdoch JMcM. The Natural Penicillins — Benzylpenicillin (Penicillin G) and Phenoxymethylpenicillin (Penicillin V). In: Ball AP, Gray JA, Murdoch JMcM, editors. *Antibacterial Drugs Today* [Internet]. Dordrecht: Springer Netherlands; 1978 [cited 2026 Jan 2]. p. 6–18. Available from: https://doi.org/10.1007/978-94-011-8004-7_3
- [12] Whiteman PA, Abraham EP, Baldwin JE, Fleming MD, Schofield CJ, Sutherland JD, et al. Acyl coenzyme A: 6-aminopenicillanic acid acyltransferase from *Penicillium chrysogenum* and *Aspergillus nidulans*. *FEBS Lett*. 1990 Mar 26;262(2):342–4.
- [13] Tobin MB, Fleming MD, Skatrud PL, Miller JR. Molecular characterization of the acyl-coenzyme A:isopenicillin N acyltransferase gene (penDE) from *Penicillium chrysogenum* and *Aspergillus nidulans* and activity of recombinant enzyme in *Escherichia coli*. *J Bacteriol* [Internet]. 1990 Oct [cited 2025 Dec 28]; Available from: <https://journals.asm.org/doi/10.1128/jb.172.10.5908-5914.1990>
- [14] Barredo JL, van Solingen P, Díez B, Alvarez E, Cantoral JM, Kattavilder A, et al. Cloning and characterization of the acyl-coenzyme A: 6-aminopenicillanic-acid-acyltransferase gene of *Penicillium chrysogenum*. *Gene*. 1989 Nov 30;83(2):291–300.
- [15] Brice K. Penicillin: A Biochemical Perspective [Internet]. ChemTalk. 2024 [cited 2025 Dec 28]. Available from: <https://chemistrytalk.org/penicillin-a-biochemical-perspective/>
- [16] Gene Clusters for Beta-lactam Antibiotics and Control of their Expression: Why have Clusters Evolved, and from where did they Originate? ResearchGate [Internet]. 2025 Aug 5 [cited 2025 Dec 28];



Available from: https://www.researchgate.net/publication/7143869_Gene_Clusters_for_Beta-lactam_Antibiotics_and_Control_of_their_Expression_Why_have_Clusters_Evolved_and_from_where_did_they_Originate

[17] Fierro F, Vaca I, Castillo NI, García-Rico RO, Chávez R. *Penicillium chrysogenum*, a Vintage Model with a Cutting-Edge Profile in Biotechnology. *Microorganisms*. 2022 Mar;10(3):573.

[18] Ph.D DTM MD. News-Medical. 2010 [cited 2025 Dec 28]. Penicillin Production. Available from: <https://www.news-medical.net/health/Penicillin-Production.aspx>

[19] Sawant AM, Navale VD, Vamkudoth KR. Isolation and Molecular Characterization of Indigenous *Penicillium chrysogenum/rubens* Strain Portfolio for Penicillin V Production. *Microorganisms*. 2023 May;11(5):1132.

[20] Nahm H, Oppermann A, Hoffmann H, Kornlein M, Oppinger H. Mercapto-phenoxy-methyl-penicillins [Internet]. US3461116A, 1969 [cited 2025 Dec 28]. Available from: <https://patents.google.com/patent/US3461116A/en>

[21] Hano T, Ohtake T, Matsumoto M, Ogawa S ichi, Hori F. Extraction of Penicillin with Liquid Surfactant Membrane. *J Chem Eng Jpn*. 1990;23(6):772–5.

[22] Edmundowicz JM, Allanson EE. Non-extractive penicillin V recovery process [Internet]. US4354971A, 1982 [cited 2025 Dec 28]. Available from: <https://patents.google.com/patent/US4354971A/en>

[23] de Barros ANC, Santos EFQ, Rodrigues DS, Giordano RLC, de Pádua TF. Hydrophobic Adsorption Followed by Desorption with Ethanol–Water for Recovery of Penicillin G from Fermentation Broth. *ACS Omega*. 2020 Apr 7;5(13):7316–25.

[24] Hodge EB. Process for preparing pure, crystalline penicillin salts [Internet]. US2520098A, 1950 [cited 2025 Dec 29]. Available from: <https://patents.google.com/patent/US2520098A/en>

[25] Haque MA, Nath ND, Johnston TV, Haruna S, Ahn J, Ovissipour R, et al. Harnessing biotechnology for penicillin production: Opportunities and environmental considerations. *Sci Total Environ*. 2024 Oct 10;946:174236.

[26] Good Manufacturing Practices [Internet]. [cited 2025 Dec 29]. Available from: <https://www.who.int/teams/health-product-policy-and-standards/standards-and-specifications/norms-and-standards/gmp>

[28] Q7 Good Manufacturing Practice Guidance for Active Pharmaceutical Ingredients Guidance for Industry. 2016;

[29] Fabio P, Alessandro C, Stefania S, Iolanda G, Elena M, Aldo C. The requirements for manufacturing highly active or sensitising drugs comparing Good Manufacturing Practices. *Acta Bio Medica Atenei Parm*. 2019;90(2):288–99.

[30] TRS 957 - Annex 2: WHO good manufacturing practices for active pharmaceutical ingredients (bulk drug substances) [Internet]. [cited 2025 Dec 29]. Available from: <https://www.who.int/publications/m/item/annex-2-trs-957>

[31] SynArchive. (n.d.). Synthesis of Penicillin V by John C. Sheehan (1957). <https://www.synarchive.com/syn/95>

[32] Bell, R. A., Britten, J. F., Howard-Lock, H. E., Lock, C. J. L., & Schmidt, M. (1994). The interaction of D-penicillamine with aldehydes and ketones: 2-phenyl-5,5-dimethylthiazolidine-4-carboxylic acid. *Canadian Journal of Chemistry*, 72, 1621–1626. <https://doi.org/10.1139/v94-203>

[33] Nakamura, R., & Fujishiro, T. (2025). Visualizing thiazolidine ring formation in the reaction of D-cysteine and pyridoxal-5'-phosphate within L-cysteine desulfurase SufS. *Biochemical and Biophysical Research Communications*, 754, 151497. <https://www.sciencedirect.com/science/article/pii/S0006291X25002116>

[34] Sheehan, J. C., & Henery-Logan, K. R. (1959). The total synthesis of penicillin V. *Journal of the American Chemical Society*, 81, 3089–3094. <https://pubs.acs.org/doi/10.1021/ja01521a044>



- [35] Pan, X., Xu, L., Li, Y., Wu, S., Wu, Y., & Wei, W. (2022). Strategies to improve the biosynthesis of β -lactam antibiotics by penicillin G acylase: Progress and prospects. *Frontiers in Bioengineering and Biotechnology*, 10, 936487. <https://doi.org/10.3389/fbioe.2022.936487>
- [36] Microbe Notes. (2023, August 3). Microbial production of penicillin. <https://microbenotes.com/microbial-production-of-penicillin/>
- [37] Pharmacy180. (n.d.). SAR of penicillins. <https://www.pharmacy180.com/article/sar-of-penicillins-2363/>
- [38] Levison ME, Levison JH. Pharmacokinetics and Pharmacodynamics of Antibacterial Agents. *Infectious Disease Clinics of North America*. 2009;23(4):791-815. doi:<https://doi.org/10.1016/j.idc.2009.06.008>
- [39] Bush K. Antibiotic and Chemotherapy. 9th ed. (Finch RG, Greenwood D, Norrby SR, Whitley RJ, eds.). W.B. Saunders; 2011:200-225. <https://www.sciencedirect.com/science/chapter/edited-volume/abs/pii/B9780702040641000142>
- [40] Bonniface Obura, Unsworth J, Jimenez-Valverde A, et al. Pharmacokinetics of Intrapartum Benzylpenicillin: Insights Into Candidate Regimens to Prevent Early Onset Neonatal Group B Streptococcus Disease. *CPT: Pharmacometrics & Systems Pharmacology*. Published online July 8, 2025. doi:<https://doi.org/10.1002/psp4.70072>
- [41] Rasmussen HC, Hanberg P, Lilleøre JG, et al. Penicillin concentrations in bone and subcutaneous tissue: A porcine microdialysis study comparing oral and intravenous treatment. *Journal of Orthopaedic Research*. 2024;42(12):2844-2851. doi:<https://doi.org/10.1002/jor.25947>
- [42] Josefsson K, Bergan T. Pharmacokinetics of phenoxymethylpenicillin in volunteers. *Chemotherapy*. 1982;28(4):241-246. doi:<https://doi.org/10.1159/000238084>
- [43] Farrington M. Clinical Pharmacology. 11th ed. (Bennett PN, Brown MJ, Sharma P, eds.). Churchill Livingstone; 2012:173-190. <https://www.sciencedirect.com/science/chapter/edited-volume/abs/pii/B9780702040849000525>
- [44] Bereda G. Clinical Pharmacology of Ampicillin. *Journal of Pharmaceutical Research & Reports*. 2022;3(3):1-3. doi:[https://doi.org/10.47363/jprsr/2022\(3\)129](https://doi.org/10.47363/jprsr/2022(3)129)
- [45] Cole M, Kenig MD, Hewitt VA. Metabolism of Penicillins to Penicilloic Acids and 6-Aminopenicillanic Acid in Man and Its Significance in Assessing Penicillin Absorption. *Antimicrobial Agents and Chemotherapy*. 1973;3(4):463-468. doi:<https://doi.org/10.1128/aac.3.4.463>
- [46] Haginaka J, Wakai J. Liquid chromatographic determination of ampicillin and its metabolites in human urine by postcolumn alkaline degradation. *The Journal of pharmacy and pharmacology*. 1987;39(1):5-8. doi:<https://doi.org/10.1111/j.2042-7158.1987.tb07152.x>
- [47] Sjoval J, Westerlund D, Alvan G. Renal excretion of intravenously infused amoxycillin and ampicillin. *British Journal of Clinical Pharmacology*. 1985;19(2):191-201. doi:<https://doi.org/10.1111/j.1365-2125.1985.tb02631.x>
- [48] Kushwaha A, Gupta P. Amoxicillin: Mechanism of action, Pharmacokinetics, and Therapeutic Implications in Bacterial Infections - PEXACY International Journal of Pharmaceutical Science. PEXACY International Journal of Pharmaceutical Science. 2023;2(6):42-64. <https://pexacy.com/amoxicillin-mechanism-of-action-pharmacokinetics-and-therapeutic-implications-in-bacterial-infections/>
- [49] Szultka M, Krzeminski R, Jackowski M, Buszewski B. Identification of In Vitro Metabolites of Amoxicillin in Human Liver Microsomes by LC–ESI/MS. *Chromatographia*. 2014;77(15-16):1027-1035. doi:<https://doi.org/10.1007/s10337-014-2648-2>
- [50] Sauberman JB, Bradley JS. Principles and Practice of Pediatric Infectious Diseases. 5th ed. (Fischer M, ed.). Elsevier; 2018:1499-1531.e3. doi:<https://doi.org/10.1016/b978-0-323-40181-4.00292-9>
- [51] Kamalpersad K, Luna G, Sunderland B, Czarniak P. An Evaluation of Amoxicillin/Clavulanate Stability in Aqueous Systems, Including Its Suitability for Outpatient Parenteral Antimicrobial Therapy (OPAT). *Drug Design Development and Therapy*. Published online September 1, 2024:4291-4301.



doi:<https://doi.org/10.2147/dddt.s474850>

[52] Bush K, Bradford PA. β -Lactams and β -Lactamase Inhibitors: An Overview. Cold Spring Harbor Perspectives in Medicine. 2016;6(8):a025247. doi:<https://doi.org/10.1101/cshperspect.a025247>

[53] Guignard B, Entenza JM, Moreillon P. β -lactams against methicillin-resistant *Staphylococcus aureus*. Current Opinion in Pharmacology. 2005;5(5):479-489.

doi:<https://doi.org/10.1016/j.coph.2005.06.002>

NOT NEW AND NOT IMMUNE: HOW CRYPTO RECREATED TRADITIONAL BANK RUN DYNAMICS

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Abstract

The 2022 collapses of Terra-Luna and FTX showed that crypto-adjacent institutions are not immune to the bank run fragility, a problem that has long dogged traditional financial institutions. This paper explores why institutions that presented themselves as distant from conventional banking structures failed in a manner that mirrored the classic bank run dynamics of 100 years ago. Through the use of qualitative comparative case studies based on Diamond-Dybvig theory and shadow banking literature, the paper applies a five-factor run-risk framework (first-mover advantage, liquidity mismatch, confidence fragility, feedback loops, and absence of backstop) to understand both collapses. The analysis shows that algorithmic pegs, opaque financial structures, and continuous redemption access amplified panic in ways structurally identical to traditional bank runs. The paper concludes by proposing targeted regulatory reforms, including reserve audits, custody separation, stress testing, and liquidity requirements within the crypto space, to reduce the potential for run risk in bank-like crypto institutions.

Keywords

Bank run fragility; Financial instability; Cryptocurrency; Crypto regulation; Banking regulation

Introduction

Cryptocurrency's promise from its inception was that it offered a clean break from many of the problems and constraints of traditional financial institutions. Its strongest proponents highlighted characteristics such as how blockchains reduce intermediaries, the ability of stablecoins to protect value, and that crypto operates around the clock, thereby offering efficiency multiples no other assets could claim. However, the year 2022 was a harsh wake-up call for such predictions. When FTX and Terra-Luna collapsed, these two institutions did not fail in any new or novel way; they failed like banks, and they failed rapidly. This paper argues that the 2022 crypto collapses demonstrate that bank run fragility is not a relic of traditional finance, but a structural feature of any system built on demandable claims without stabilizing institutions.

This fact raised a crucial question: why did the organizations that did their best to distance themselves from traditional finance collapse in a manner that very closely mirrored a classic bank run from the 20th Century? Answering this question requires one to shift the question away from supposed technological innovation into an area that has gained less attention: structure. The key is to think of banks more broadly. Banks aren't simply about things like deposit slips or an imposing vault; they are institutions that offer a venue to place assets for a period of time, which can then be redeemed at full value (these are known as demandable claims). Due to a history of crises, modern banks have a number of safeguards in place to prevent runs; Crypto institutions, like FTX and Terra-Luna, did not.

Crypto's confidence, some would label it arrogance, that technology could substitute for these safeguards meant disaster was only one short panic away, and 2022 would reveal how true this was. Fundamental to any crypto assets' success was one crucial element – confidence – and when this dissipated, the collapse was rapid and catastrophic. Customers were highly rational: exiting early and leaving others with depreciating asset claims. Blockchain transparency, which was meant to improve confidence and clarity, supercharged this trend by making exits highly visible.

The collapse of Terra-Luna and FTX occurred very quickly. Terra-Luna collapsed between 7 May and 12 May 2022, losing more than \$40bn after the peg collapsed. FTX filed for Chapter 11 bankruptcy on 11 November 2022, a mere nine days after CoinDesk's disastrous story on the company's financial status. This was a vivid illustration of a system built without circuit breakers, opaque balance sheets, and an expectation of constant, on demand liquidity, all in an environment where hesitation meant losing money when the tide turned. In such an environment, the panic was not an aberration or some malfunction, rather, it was the predictable outcome of a design. In the popular imagination, the 2022 crypto scandals were a result of managerial incompetence or fraud. While these elements were definitely present, particularly in the case of FTX, they don't fully explain why panic spread so rapidly and why these institutions collapsed so rapidly. This paper argues that the 2022 crypto collapse illustrates vividly that bank run fragility is not some artifact from the distant past that has no impact on the current crypto space. In fact, it is a structural feature that is highly relevant, since many crypto institutions are built on runnable liabilities that do not have backstops. So, rather than crypto escaping the risks of traditional finance, it has rediscovered one of its most dangerous lessons.

An Introduction to Bank run Dynamics

In popular imagination, a bank run is usually thought of as a chaotic line of people lining up to withdraw money from a bank. While this image is partially correct, it misses the primary cause of the bank run in the first place, which is when the financial structure of an institution results in it being unable to satisfy short-run claims through assets that cannot be easily changed into cash (Friedman, 1977). In such a situation, when there is a lack of confidence due to endogenous shocks, people will have the incentive to rapidly withdraw their funds, leading to a self-reinforcing process that ultimately causes collapse.

The Diamond-Dybvig model shows how fundamentally solvent banks before a crisis can also collapse in such a situation (Diamond, 2007). The mechanics are as follows. Depositors need access to their money on short notice, but the banks have invested the deposits in longer-dated assets which have better returns. This works as long as there is trust that not everyone will withdraw money at once. When a crisis emerges, this trust cracks, and withdrawing money becomes the safest option for depositors. While banks do keep a certain number of reserves to cover such times, there are limits. Once these limits are reached, the bank will be forced to begin liquidating longer-dated assets. If this liquidation is not done quickly enough, panic ensues, and a bank run transpires. So this means that a bank run doesn't actually need a bank to be "bankrupt" because it is the panic itself that causes the disaster.

Deposit insurance is meant to provide peace of mind and limit the incentive to withdraw cash. Lenders of last resort, like Central Banks, stand ready to provide emergency liquidity should the need arise. Financial authority-mandated capital and liquidity reserves are aimed at providing some kind of buffer to banks that are facing increased demands for cash (Andolfatto et al., 2017). Together, these tools are meant to calm things when financial conditions are worsening.

As our financial systems have evolved, there has been a move toward a shadow banking system. The Financial Stability Board defines shadow banking as "credit intermediation involving entities and activities outside the regular banking system ... Such intermediation can support economic activity by providing additional funding sources for the economy, including for riskier market segments that may find it relatively difficult to access bank funding" (Manalo et al., 2015). But these institutions are not immune to bank runs, and are arguably at even more risk. Due to the lack of traditional protection tools outlined above, loose to no regulation, and opaque financial statements, these institutions are deeply at risk of margin calls, refusals to roll over short-term funding, or greater collateral requirements when a crisis emerges, thus placing them in danger of collapse (Gorton & Metrick, 2010). The fundamental mechanism of collapse is the same: rapid claims for cash lead to instability when confidence breaks down.

Understanding this broader phenomenon is crucial for analyzing crypto-related financial failures. While many crypto institutions like to think of themselves as being new paradigms in the world of finance, the reality is that they have recreated many of the features of traditional banks. Stablecoins, centralized crypto lenders, and exchanges all share a common feature (along with banks): they issue claims users believe to be liquid and rapidly redeemable. In other words, the perception is that when you want access to your

money, you shall have it. In parallel to this perception is the reality that these crypto institutions often use these funds and then invest them in other volatile, leveraged, or illiquid assets (Azar et al., 2024). This combination of a mismatch between demandable claims and institutionally difficult-to-access funding in certain conditions made crypto ripe for bank run type behavior. What makes things worse is that none of the traditional hedges against bank runs exist.

Thus, a completely new way of analyzing crypto failure is not necessary, because they share most of the characteristics of a traditional bank run. The World Economic Forum defines a bank run as “when a bank faces a loss of confidence, sparking many customers to withdraw their deposits ... [with] massive withdrawals happening simultaneously put the bank’s existence at risk ... [creating] fears, and contagion [that] can spread from one institution to another, undermining the banking system as a whole” (Charlton, 2023). It is important to note that whether the institution meets the legal definition of a bank is irrelevant; the key is in terms of how claims and assets are structured, and how participants respond to uncertainty during periods of turmoil.

Five key elements are typically present and are important in building “run risk.” Firstly, there must be a first-mover advantage during times of crisis. If there seems to be a crisis that can lead to collapse, then the depositors who withdraw their funds the quickest will have the biggest advantage. Secondly, there needs to be a mismatch in terms of liquidity/asset maturity, and this difference means that mass withdrawals cannot be satisfied with existing assets or only through selling these assets at a huge loss. Thirdly, there needs to be concerns about the solvency of the institutions, resulting in confidence being even more fragile. Fourth, there needs to be a vicious cycle that occurs as withdrawals force institutional asset sales at depressed prices that further weaken balance sheets and lead to further panic. Finally, there should be no credible support system that could step in and slow the chaos (Azar et al., 2024).

The crypto space intensifies these issues due to the characteristics of the institution itself. Many crypto-related institutions are very opaque, with little public information available about reserves, quality of assets, or interconnections within the broader crypto universe. In addition, many crypto platforms emphasize the fact that they run 24/7, which accelerates the speed of collective exits in times of crisis. Finally, as previously mentioned, there are no institutional safeguards behind most crypto institutions, unlike their traditional financial peers. As a result, once confidence erodes, there are few barriers to a rapid collapse. When considering crypto collapses through this lens, it changes the way policymakers examine these phenomena. Rather than isolated scandals or failures in management, these collapses can be thought of as predictable outcomes of structures that are ill-fitting and ripe for problems, primarily due to their fundamental design. While crypto enthusiasts might like to project an image of innovation and dynamism, the crypto space has important flaws baked into its DNA, particularly during times of crisis.

The collapse of Terra-Luna and FTX offers important lessons and a vivid illustration of how run dynamics can emerge even in decentralized systems built around stable-value promises. Together, these case studies demonstrate that the fundamental logic of bank runs remains powerful, even in financial systems that claim to have moved beyond traditional banking.

Methods

I used a qualitative and theory focused approach to understand the causes behind the 2022 crypto market crash. Instead of using original data, this paper uses a combined approach from three different sources. First, the paper uses established frameworks from the existing banking and financial literature, in particular, the Diamond-Dybvig bank-run theory and shadow banking related literature. This background allows for an analytical framework that we can use to explore crypto institutional failures. It also allows us to identify structural parallels between the traditional banking sphere and crypto. Second, the paper uses a comparative case study between Terra-Luna and FTX. These cases were specifically selected because they represent particular institutional models of decentralized finance (DeFi) and centralized finance (CeFi). Despite their differences, they both exhibited classic bank-run dynamics. Each of the case studies are analyzed through the five-factor run-risk framework, which includes first-mover advantage, liquidity mismatch, confidence fragility, feedback loops, and absence of a backstop authority. Each factor was

evaluated in terms of both cases through examining whether the structural conditions necessary for that element were in existence and, if they were, how they interacted with other elements to form or supercharge the run dynamic. Sources that were secondary in nature were chosen if they had proximity to the event and possessed methodological rigor. So, research studies that were widely cited were chosen, as well as reports from well-regarded institutions like the Federal Reserve or Financial Stability Board. Thirdly, this paper uses secondary sources to reinforce the research conclusions from the two case studies.

Results

Case Study I: Terra-Luna

The spectacular collapse of Terra-Luna in May 2022 offers one of the sharpest examples of how bank run dynamics can emerge in the crypto space, with devastating consequences. This collapse destroyed more than \$40 billion in value and upended the entire crypto ecosystem, resulting in the failure of a number of crypto-adjointing institutions (Lee et al., 2023). Terra-Luna's collapse is now seen as an important cautionary tale of how bank run dynamics can occur outside the traditional banking system. While regulators have focused on the fraud and misrepresentation that occurred, particularly those of its founder, Do Kwon, the structural impetus behind Terra's implosion was driven by many familiar forces: erosion of confidence, a mad rush to redeem money-like claims, and the absence of any stabilizing institutions.

It is important to understand the mechanics of Terra-Luna because, while the company proudly extolled its innovation, this so-called innovation obscured real fragility. Terra was constructed around an "algorithmic stablecoin" called TerraUSD (UST). The Crypto Council for Innovation defines algorithmic stablecoins as "a digital asset that mirrors the price of a fiat currency, usually the US dollar. Using mechanisms that adjust the circulating token supply, these types of stablecoins attempt to maintain their peg with the underlying currency" (Ekshian, 2025). These types of coins are different from reserve-backed coins such as USDC or USDT, which are actually backed by real assets (US dollars, bonds, treasuries, etc.). The maintenance of value for UST was supported through its relationship with its sister token, Luna.

What was meant to occur was that when UST traded below \$1, traders could buy UST cheaply (e.g., for \$0.97). These same traders would then redeem that 1 UST for \$1 worth of Luna, and then sell that Luna on the open market for US dollars, pocketing the difference. This process would burn (remove) UST from circulation, reducing supply and pushing the price back toward \$1. When UST traded above \$1, traders could buy \$1 worth of Luna to mint 1 UST and sell that UST on the open market for more than \$1 (e.g., \$1.02), keeping the difference. This process would increase the supply of UST and push the price down toward \$1 (Naudts & Jouanneau, 2022). This entire process created the illusion of stability within the system.

UST was essentially a demandable liability. Users treated it like "real" money: They believed it would always be available, always be redeemable, and would always retain its value. In addition, there was one other issue lurking within the Terra-Luna ecosystem—the Anchor Protocol. Anchor offered around 20% yields on UST deposits, which encouraged users to park their UST with Anchor in the face of excellent returns. There was a sense of complacency and confidence that UST would hold its peg and users would be able to attract very favorable returns at the same time. Over time, the supply of UST expanded dramatically, with many investors believing they had found an amazing opportunity, a low-risk and high-interest way to save money that seemed extremely liquid (Briola et al., 2023). This introduced further risk into the system when users began to treat Terra-Luna like a reliable savings product, akin to a bank. What many didn't know is that the favorable saving rates offered by Anchor weren't the result of standard bank lending practices but were, in fact, the result of subsidization by Terraform Labs (the originators of Terra-Luna) and outside investors. This subsidization would be a major problem later when withdrawals became so excessive there was no way to cover the promised interest payments.

A further weakness came from how withdrawals were funded. UST was redeemable for Luna at any time, meaning that whenever users exited UST, the protocol removed their UST and minted new Luna to maintain the peg. To turn that value into cash, traders then had to sell the newly minted Luna on the open market. When Terra was young, this was not a problem because Luna was valuable and there was a limited supply

of UST. However, in 2022, UST had grown by orders of magnitude and, like the broader crypto market, Luna's price was becoming more and more unstable. Now, rather than acting like a stabilizing force or reserve that it was supposed to, Luna was injecting instability. When UST slipped its peg in May 2022 (this had happened on a number of occasions prior, but had self-corrected in the past), the system created a huge amount of Luna to compensate. With such a deluge of tokens entering the market, the price of Luna collapsed, and a classic bank run began as first movers all attempted to exit as quickly as possible. The innovation of Terra-Luna, its algorithm, created the fatal flaw through a faulty mechanism for how withdrawals were funded (Briola et al., 2023).

When viewed through the standard framework of run risk, Terra-Luna contained all the ingredients necessary for a destructive bank run, amplified by Anchor's incentive structure. The structure of Terra-Luna created extreme liquidity mismatches. While the vast majority of UST sat in Anchor for its excellent yield, withdrawals could only be met through the protocol's burn-and-mint mechanism, whereby exiting users burned UST and received newly issued Luna. In short, there were not enough funds but the system needed to create it if there was a demand for it. Once large-scale withdrawals began, the value of that newly minted Luna fell rapidly, making it increasingly difficult for users to exit at full value. There was also a distinct first-mover advantage. Those who withdrew UST and redeemed it earliest would receive the highest value because Luna was losing value as redemptions grew.

The system was driven by confidence in the system, and once that failed, it sent a cascade of withdrawals into the system. When news began to emerge that Anchor's yield was subsidized, users began to connect the dots and see that eventually they would not be able to receive their returns; this shook the community's confidence. There was no lender of last resort or insurance to backstop deposits. Once a run began, there was no way to slow it down or calm fears by appealing to a central bank. Each owner of Terra-Luna was completely at the mercy of the markets.

Case Study II: FTX

2022 was a very difficult year for those in the crypto space. In November 2022, FTX, one of the world's largest cryptocurrency exchanges, collapsed in a matter of days. This collapse had many of the hallmarks of bank run dynamics from a hundred years prior and illustrated that these collapses could occur even in institutions that prided themselves on being distinct from traditional financial institutions. What made FTX's collapse particularly notable was its sheer size: At its peak, FTX was valued at tens of billions of dollars and had millions of customers around the world (Fu et al., 2024).

FTX prided itself on accepting consumer deposits in a number of cryptocurrencies and stablecoins. Customers were assured that they would access their funds 24/7 and in a rapid manner. This meant that FTX faced a very large pool of demandable deposits. Importantly, these deposits were believed to be highly liquid and safe by users. This would be crucial to the eventual collapse, and it matches the dynamic seen in other run scenarios: seemingly liquid deposits backed by illiquid assets. These illiquid assets would be a disaster for FTX (Fu et al., 2024). But FTX's issues did not end there. A major source of danger for the organization was its close association with Alameda Research. Alameda Research was extremely dependent financially on FTT, FTX's native token. FTT and other illiquid crypto assets created and promoted by FTX were the backbone on which Alameda was built. (Coquidé et al., 2025) Worse, the value of FTT was inextricably linked to a belief in FTX's continued financial soundness. The result was weakness and a liquidity mismatch i.e. the company's ability to meet its obligations to depositors was dependent on an asset whose value was tied to the perception of that exact organization.

On 2 November 2022, a report from CoinDesk revealed the extent of Alameda's FTT holdings. This report showed that rather than Alameda holding a basket of liquid assets, it had heavily concentrated its assets in FTT and other FTX-related tokens (Allison, 2023). This led to people worrying about the true financial status of both Alameda and FTX, and whether customer funds were being used in the right way. Around the same time, Binance, a major FTX competitor, announced it would liquidate its significant FTT holdings (TheNewsCrypto, 2022). This placed even more pressure on FTT's price, and confidence in FTX began to plummet.

At this point, just like a typical bank run, things began quickly unravelling. FTX's price collapsed and fell more than 80% within a few days of the news. This placed FTX's balance sheet under acute pressure. As users began to see how widespread the problem was, first-mover advantage took hold and withdrawals from the exchange surged in response. The fact that much of FTX's assets were locked away in illiquid crypto assets and comingled with money at Alameda meant that, as redemptions accelerated, they were unable to fund everyone's requests. Withdrawals surged, with reports suggesting that FTX saw nearly \$6bn exit the platform within days of the CoinDesk report, overwhelming its ability to process requests.

FTX wasn't able to meet this overwhelming demand, illustrating the issue of liquidity mismatch and associated problems. Importantly, this mismatch was exacerbated by governance failures that existed even before the run started. Most alarmingly, FTX operated within a meaningful divide between customer funds and the business' own funds. Customer deposits were, unknowingly, being used to fund speculative positions at Alameda Research. This violated established banking custody norms and best practices. So, when FTX needed to fund a flood of redemptions, it was unable to because these funds were locked away within illiquid and risky bets that Alameda had made. The CoinDesk report did not merely raise questions of solvency but also destroyed the foundational confidence of FTX as a bank-like institution. Customers could no longer feel certain that the assets they had placed in FTX's care were being leveraged on risky bets elsewhere. This uncertainty is precisely the mechanism the Diamond-Dybvig model identifies as the trigger for a run: when depositors cannot verify institutional soundness, early exit dominates as a rational strategy. FTX's governance failures did not just accompany the bank-run dynamic in a vacuum; they activated it through removing the information asymmetry. The collapse of FTX also illustrated how rapidly these dynamics feed on themselves. As more customers withdrew, the price of FTX fell further, which influenced the perceived stability of FTX's ability to meet obligations, which led to even more withdrawals. This caused a spiral that matches a characteristic bank run. And it was only a matter of time until whatever liquidity remained would be completely drained. That moment arrived on 11 November 2022, when FTX's liquidity position deteriorated to the point where it ceased to process customer withdrawals altogether and filed for Chapter 11 bankruptcy, along with more than 100 affiliated entities (Yaffe-Bellany, 2022). Just like in the case of Terra-Luna, the lack of stabilizers amplified the collapse. FTX had no deposit insurance or a lender of last resort it could turn to when things went badly.

As the volume of redemption surged, the company was unable to turn to a central bank or some other monetary authority for help. The final result was a complete collapse that was the result of fraudulent management and structural fragility. This fragility happened because the system was built on demandable claims that could not be met with illiquid assets. This is where the similarity to bank runs becomes the most clear. In regular banking, a tidal wave of withdrawals forces a bank to liquidate assets to meet requirements. In FTX's case, there were insufficient assets to meet this demand either because the assets themselves had shrunk substantially in value (FTT) or the original deposits had been rolled into risky investments by Alameda.

FTX's collapse shows that bank run dynamics are not limited to entities in traditional finance labelled "banks." There should be warning bells ringing when customers think their deposits are safe but these deposits are mixed with other underlying assets that have unclear value. This is even more a problem when there aren't buffers and credible backstops, because a collapse in confidence can start a rapid withdrawal spiral that can lead to disaster. It also shows that, when there is a lack of regulatory safeguards and controls, crypto companies are just as vulnerable to the same fragilities that have brought down traditional financial firms.

Discussion

Policy Implications and Recommendations

What the collapses of Terra-Luna and FTX make abundantly clear is that crypto institutions can easily be overwhelmed by bank run dynamics in the right conditions. While crypto optimists believed their technology was immune to many of the problems of traditional finance, the reality has been different. In fact, a strong argument can be made that traditional banks are safer because of the many safeguards that are currently in place. This means that for crypto to go completely mainstream, it needs to accept some level of regulation

in order to reduce the chances of massive failures on the scale of Terra-Luna and FTX. This means that policymakers should start exploring tools to lessen the impact and breadth of these problems.

An obvious place to begin would be to look at reducing the runnability of crypto assets. Transparency requirements and mandatory stress testing directly target confidence fragility and through lessening informational asymmetries that drive the incentive for early exit, also lower first-mover advantage. In the cases of both Terra-Luna and FTX, customers expected that their claims (deposits) would be instantly accessible 24 hours a day, 7 days a week. And not just accessible, but able to be withdrawn in full. In the case of mass withdrawal, there was no way either institution would be able to make good on such a claim. Policymakers should force crypto institutions to be more transparent about the fact that there is no such thing as guaranteed redemption and that these deposits face risks, just like any asset. This means these institutions also need to face stress tests (testing the institutions under a variety of hypothetical market situations), just like normal banks and the results of these tests need to be published. This also connects with crypto that markets itself as “stable,” particularly in relation to real world assets like the U.S. dollar, gold etc. These types of assets should be required to have tangible reserves of the assets they claim they are linked to. These reserves need to be independently audited and the results published publicly. If crypto assets want to be seen as “money-like assets” they need to be subject to similar money-like assessments. Institutions that refuse to be part of such controls and assessments need to broadcast this fact widely, so people do not believe they are holding something safe when in fact they are holding an asset that has a high degree of run risk.

A second reform should revolve around creating limits on custodial institutions, like FTX. Mandatory custody separation targets both liquidity mismatch (by ensuring client funds are not redeployed in illiquid assets) and confidence by providing users with verifiable assurance that their assets are held separately from corporate positions. FTX’s main weakness was that it had comingled customer assets with Alameda’s trading positions. This goes against banking best practices, which mandate the separation of customer assets and corporate funds. These rules would be similar to the custody protections in stock brokerage accounts or money market funds, where the separation and independence of assets is of utmost importance (Black, 2000).

Another option would be to apply bank-like capital and liquidity requirements to any organization that issues a claim that could be runnable, irrespective of whether it calls itself a bank or not. Such requirements help address the absence of a backstop and ensure that reserves (that are sufficiently liquid) exist before a crisis rather than requiring institutions to liquidate assets at distressed prices once a run has begun. Mandatory liquidity buffers also slow negative feedback loops because asset “fire-sales” during a run further depress prices and accelerate withdrawals. Having ready reserves slows losses of confidence before they become a self-reinforcing spiral. While crypto adjacent organizations like to think of themselves as a new paradigm, regulators could examine them in terms of function, rather than whatever label they give themselves. This means that if a firm takes funds from a customer and that customer believes he or she can withdraw those funds at short notice, then that institution should be required to hold some form of liquid reserves.

There is a tension here that is constantly debated within crypto: stability is needed, but if this stability introduces too much regulation, it might inadvertently reduce innovation and introduce moral hazard. If, for example, governments began introducing deposit insurance or the Fed agreed to be a lender of last resort, people may feel emboldened to undertake even more risky crypto ventures, safe in the knowledge that the government will step in if things go wrong. At the same time, introducing the full range of bank regulations on the sector will limit the experimentation that attracted people into the crypto space in the first place. The solution seems to be that there needs to be a laser-like focus on a particular subsection within the crypto ecosystem: those institutions that function in a bank-like manner.

Conclusion

The collapse of Terra-Luna and FTX shows how innovation cannot always escape poorly designed financial structures. While both organizations branded themselves as radical alternatives (through the algorithmic mechanisms, decentralization, 24/7 access etc.) to the traditional finance, both were brought down by

problems that have plagued traditional institutions for hundreds of years. UST was a demandable claim backed by a volatile asset, while FTX used deposits to make illiquid bets on other crypto instruments. When confidence fell apart, neither organization was able to stem the mass withdrawals that collapsed both institutions. The result was something that anyone who lived through the bank runs of the 1920s would recognize: users rushing to withdraw deposits, assets proving insufficient to meet demand. This was a very old problem that has reoccurred many times because the traditional guardrails that were meant to stop a failure of this sort happening were absent. Policies like lender-of-last-resort assistance, capital buffers, and tight custody rules were implemented in the 20th Century to stop these exact problems from occurring. Crypto seems to need to embrace at least some regulations and controls or face a future where this boom-bust cycle repeatedly plays out and destroys confidence in crypto as an asset for storing wealth.

References

- Allison, I. (2022, November 2). Divisions in Sam Bankman-Fried's crypto empire blur on his trading titan Alameda's balance sheet. *CoinDesk*. <https://www.coindesk.com/business/2022/11/02/divisions-in-sam-bankman-frieds-crypto-empire-blur-on-his-trading-titan-alamedas-balance-sheet>
- Andolfatto, D., Nosal, E., & Sultanum, B. (2017). Preventing bank runs. *Theoretical Economics*, 12(3), 1003–1028. <https://doi.org/10.3982/TE1970>
- Azar, P., Baughman, G., Carapella, F., Gerszten, J., Lubis, A., Perez-Sangimino, J., Rappoport, D. E., Scotti, C., Swem, N., Vardoulakis, A., & Werman, A. (2024). The financial stability implications of digital assets. *Economic Policy Review*, 30(2). <https://doi.org/10.59576/epr.30.2.1-48>
- Black, B. (2000). The core institutions that support strong securities markets. *The Business Lawyer*, 55(4), 1565–1607.
- Briola, A., Vidal-Tomás, D., Wang, Y., & Aste, T. (2023). Anatomy of a stablecoin's failure: The Terra-Luna case. *Finance Research Letters*, 51, 103358. <https://doi.org/10.1016/j.frl.2022.103358>
- Charlton, E. (2023, March 20). What is a bank run? And why does confidence matter for a bank? *World Economic Forum*. <https://www.weforum.org/stories/2023/03/bank-run-silicon-valley-panic/>
- Coquidé, C., Cazabet, R., & Tovanich, N. (2025). Inside Alameda Research: A multi-token network analysis. In H. Cherifi, M. Donduran, L. M. Rocha, C. Cherifi, & O. Varol (Eds.), *Complex Networks & Their Applications XIII* (pp. 200–212). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-82431-9_17
- Diamond, D. W. (2007). *Banks and liquidity creation: A simple exposition of the Diamond-Dybvig model* (SSRN Scholarly Paper No. 2186646). Social Science Research Network. <https://papers.ssrn.com/abstract=2186646>
- Ekshian, E. (2025, July 18). What is an algorithmic stablecoin? *Crypto Council for Innovation*. <https://cryptoforinnovation.org/what-is-an-algorithmic-stablecoin/>
- Friedman, B. M. (1977). Financial flow variables and the short-run determination of long-term interest rates. *Journal of Political Economy*, 85(4), 661–689. <https://doi.org/10.1086/260595>
- Fu, S., Wang, Q., Yu, J., & Chen, S. (2024). FTX collapse: A Ponzi story. In A. Essex, S. Matsuo, O. Kulyk, L. Gudgeon, A. Klages-Mundt, D. Perez, S. Werner, A. Bracciali, & G. Goodell (Eds.), *Financial Cryptography and Data Security. FC 2023 International Workshops* (pp. 208–215). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-48806-1_14
- Gorton, G., & Metrick, A. (2010). Regulating the shadow banking system. *Brookings Papers on Economic Activity*, 41, 261–312. <https://doi.org/10.2139/ssrn.1676947>
- Lee, S., Lee, J., & Lee, Y. (2023). Dissecting the Terra-LUNA crash: Evidence from the spillover effect and information flow. *Finance Research Letters*, 53, 103590. <https://doi.org/10.1016/j.frl.2022.103590>
- Manalo, J., McLoughlin, K., & Schwartz, C. (2015). Shadow banking: International and domestic developments. *Reserve Bank of Australia Bulletin*, March, 83–96. <https://www.rba.gov.au/publications/bulletin/2015/mar/8.html>
- Naudts, M., & Jouanneau, F. (2022, May 25). Deep dive: UST/LUNA explained and the future of stablecoins. *Medium*. <https://medium.com/venture-beyond/deep-dive-ust-luna-explained-and-the-future-of-stablecoins-5ec0fd3c3702>

TheNewsCrypto. (2022, November 6). Binance aims to sell all of its FTX holdings, SBF remains silent. *Binance Square*. <https://www.binance.com/en-NG/square/post/45814>

Yaffe-Bellany, D. (2022, November 11). Embattled crypto exchange FTX files for bankruptcy. *The New York Times*. <https://www.nytimes.com/2022/11/11/business/ftx-bankruptcy.html>



LIGHTS, CAMERA, ALGORITHM: THE FUTURE OF AI IN FILM PRODUCTION

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Abstract

The economic impacts – including budget management and total production costs – that AI-driven production tools have on the film industry are immense. The paper will analyze the Netflix TV show *The Eternaut* and the AI-powered film, television, and gaming studio Staircase Studio to investigate the benefits AI offers. Industry data, such as market growth analysis, and expert perspectives from James Cameron and Ted Sarandos, will be incorporated for a more comprehensive evaluation of AI implementation and the ensuing public reaction. It will then weigh the numerous benefits and harms AI brings to the future of the film industry, representing diverse and various voices. To conclude, the paper will examine the implications that today's AI presents to the film industry, which are simultaneously applicable to the broader world. This discussion will give the readers a sense of what to expect in the future that will be predominantly permeated by AI.

Keywords

Artificial Intelligence; film industry; filmmaking; future potential; Netflix; Staircase Studio

Introduction

What seems real is revealed as fake more often than not, and the boundary between the two is increasingly blurred by Artificial Intelligence (AI), to a concerning extent. Immensely significant and widely applicable, AI is rapidly pervading practically all industries, and the film industry is no exception. In many current applications, AI in film production is not about replacing the director's creativity or the cast's talent, but about complementing their work and "achieving more with less" (Medium). Nevertheless, its potential to outright replace people's jobs is a growing concern. The tasks AI-driven production tools perform include creating realistic character animations, generating complex visual effects, enhancing image resolution, and assisting with tasks like 3D model generation and texturing (Medium).



Figure 1: Marvel's *Secret Invasion* Opening Credits, Entirely Created by AI

AI-assisted and AI-driven production tools are starting to change the essence of contemporary film entirely as seen in Figure 1. AI is being rapidly integrated into the production processes of films – pre-production in particular – prompting crucial economic questions: who will benefit from these tools, and how will those benefits be distributed across the industry? AI lowers barriers to entry for small, independent filmmakers by making visual effects, editing, and virtual production processes more accessible. Yet, the greatest short-term economic gains are likely to head toward large studios that have the capital and infrastructure necessary to maximize the tools' efficiency. In this light, AI may democratize access to certain production capabilities, but this does not necessarily entail democratizing economic and market power. Hence, its long-term impacts will depend not merely on its technological capabilities, but also on who controls it, to what extent human labor will be protected, and whether AI will be used to improve human work or replace it entirely. In this paper, AI-assisted refers to tools that support human creators in tasks such as image enhancement or sound cleanup, while AI-driven refers to systems that independently generate substantial creative products such as AI-generated images, voices, scripts, or effects with reduced human input. Likewise, the term democratization does not necessarily mean equal economic benefit; rather, it refers to broader access to production capabilities and lower-cost creative tools. Access to technology may increase even when ownership of capital and market power remains concentrated among larger firms.

Methods

This paper will utilize two case studies for comparison and consideration of the use of AI in the film industry.

Case Studies

The virtual production stage of filmmaking offers significant cost-saving opportunities, particularly in effects-heavy sequences that would otherwise require expensive location work or labor-intensive postproduction. One major example is Netflix's use of generative AI in *The Eternaut* to depict a collapsing building in Buenos



Aires. According to Ted Sarandos, the sequence was completed “10 times faster” than it would have been through traditional workflows. However, this figure should be interpreted carefully. A tenfold increase in speed may indicate that AI is most effective at accelerating repetitive or technically demanding VFX tasks, rather than replacing the creative decision-making involved in designing the scene itself. In other words, AI may optimize execution more than imagination. Even so, for a large company like Netflix, this efficiency translates into a major economic advantage: the studio can produce visually ambitious content at lower cost while still maintaining a polished final product.

The virtual production stage of filmmaking presents numerous opportunities to save costs through the use of AI. While location shooting is one of the most expensive parts of film production, virtual production can effectively mitigate high costs by recreating the environment digitally. This type of replacement has been seen in a number of films. For example, Netflix used generative AI for the first time in one of its TV shows, *The Eternaut*, “to show a building collapsing in Buenos Aires” (The Guardian). This was done in partnership with Scanline VFX and Netflix’s creative team. Netflix co-chief executive Ted Sarandos later revealed that “using AI-powered tools, they were able to achieve an amazing result with remarkable speed, and that VFX sequence was completed 10 times faster than it could have been completed with traditional VFX tools and workflows.” He said the use of AI enabled Netflix to fund the show at a much cheaper cost than is usual for a large-scale production of the like, and that it included effects that would not have been feasible on the show’s budget. However, this number should be interpreted carefully. A tenfold increase in speed may indicate that AI is most effective at accelerating repetitive or technically demanding VFX tasks, rather than replacing the creative decision-making involved in designing the scene itself. In other words, AI may optimize execution more than imagination. Even so, for a large company like Netflix, this efficiency translates into a major economic advantage: the studio can produce visually ambitious content at lower cost while still maintaining a polished final product.

Another example is Staircase Studio, an AI-based film, television, and gaming studio. According to The Australian, Staircase Studio can reduce production costs from \$500,000-\$1 million per minute to \$10,000-\$20,000 per minute. This, however, requires qualification. Cost reductions, especially on such scale, would only be meaningful if the resulting output quality and theatrical viability are not harmed. Currently, such models appear feasible for short-form or experimental content rather than for every premium cinematic production. Such limitation notwithstanding, the case remains significant because it demonstrates AI’s potential to make high-quality visual storytelling more accessible to independent creators who previously lacked the resources to compete. This can, therefore, help bridge the gap between dominant studios and small filmmakers, bringing new perspectives to the industry.

Results and Discussion

Industry Data

The Morgan Stanley Report shows that AI-driven generative tools could reduce expenses in TV and film by up to 30%, with average cost cuts of ~10% across media industries. With the advent of AI, new and smaller companies should be able to leverage technology to produce high-quality content, challenging the major leaders of the industry. Another report by Market.us, seen in Figure 2, projects that the global AI in the film market will reach \$14.1 billion by 2033. The factors driving this growth include the “demand for enhanced efficiency and cost reduction in film production, the capability of AI to generate detailed and realistic visual effects, and the growing need for personalized content on streaming platforms.”

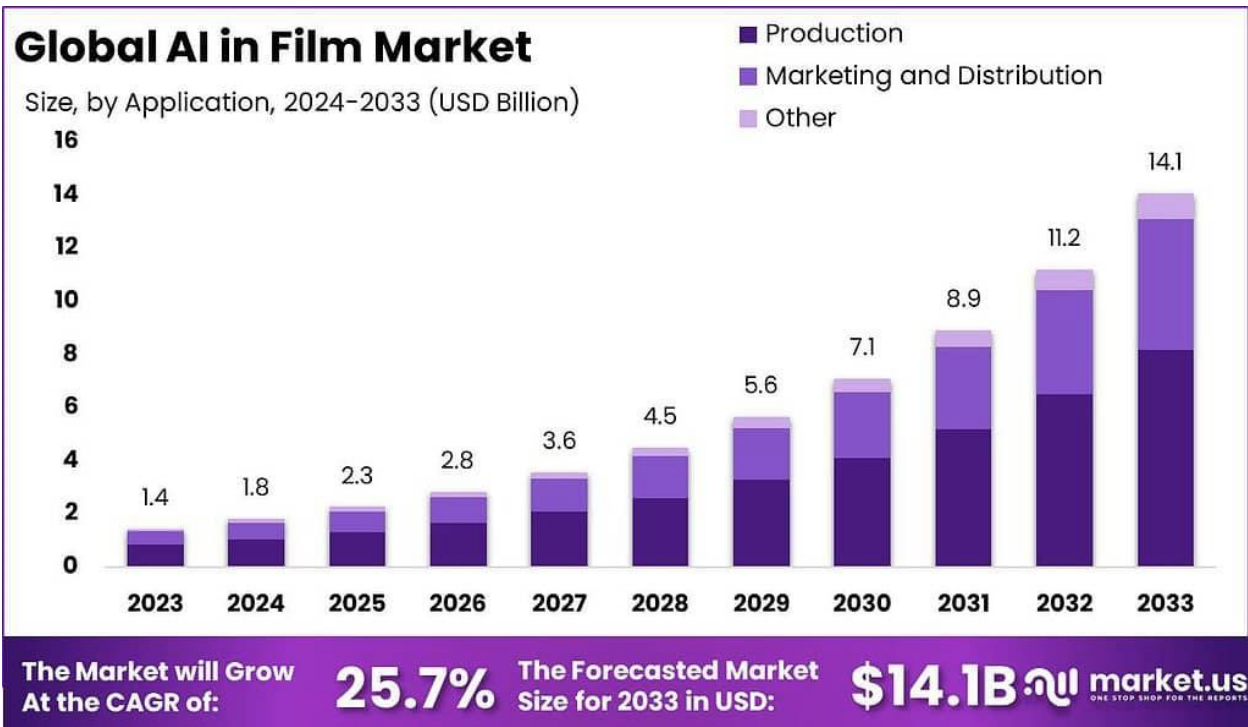


Figure 2: Graph indicating the projected growth of global AI in the film industry

In particular, the market for generative AI in movies is projected to grow from \$481 million in 2024 to \$4.49 billion in 2033 – as shown in Figure 3 – indicating a nearly 10× increase over the decade. These two graphs highlight an aggressive compound annual growth rate (CAGR) and reflect the increasing economic significance of AI in filmmaking.

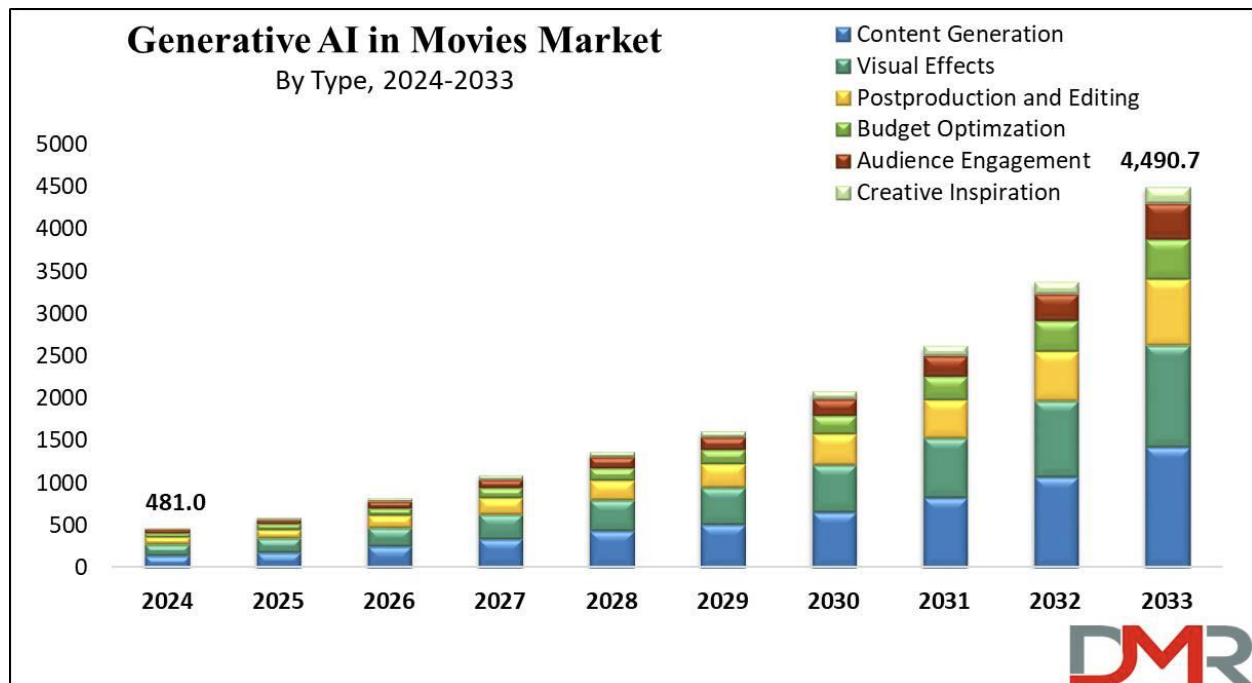


Figure 3: Graph indicating projected growth of generative AI in the film industry



Limitations and Ethical Trade-offs

Unfortunately, immense change brings not only benefits but also harms and trade-offs. These include concerns for job displacement, creative ownership issues, and loss of artistic integrity. First and foremost, AI's efficiency threatens jobs. Labor unions and artists fear job losses, "with a 2024 study estimating 204,000 Hollywood roles – especially in VFX and postproduction – at risk" (Medium). Also, a 2024 study found 77% of 300 industry leaders employed AI to supplant human roles, particularly in VFX, sound engineering, and concept art (The Hollywood Reporter). Such a plethora of job losses leads to concerns for creative authenticity. According to Reuters, the 2023 Hollywood strikes made AI one of the industry's most urgent labor issues, as unions pushed for contractual protections against the unauthorized use of performers' likenesses, voices, and creative labor. This reveals that the economic question is not only whether AI reduces costs, but also whose labor becomes more vulnerable in the process. If studios use AI primarily to weaken bargaining power or replace specialized creative roles, the financial gains generated by the technology will be distributed upward rather than shared across the workforce. USC's Jonathan Taplin claims AI's range of generating content is limited, aggravating the originality of media (MIT Sloan). James Cameron, via Variety, expressed skepticism about AI writing scripts that can move audiences, referring to their reliance on recycled, repetitive ideas (Variety). BGR notes public backlash against the AI visuals in "Late Night With the Devil," where AI-generated transitional graphics sparked boycott threats (BGR). Audience response suggests that viewers do not reject all AI uses in film equally. Survey evidence indicates that audiences are generally more comfortable with AI in supportive or background functions than in generating core creative elements such as actors or major visual content (YouGov). Acceptance also appears to increase when AI involvement is clearly disclosed and transparent. By contrast, backlash surrounding films such as *Late Night with the Devil* suggests that viewers are more resistant when AI use is clear and appears to supplant human labor. Not only the public, but voice actors expressed their concerns regarding AI as well. Rehlinger, a French voice actor renowned for his dubbing for Ben Affleck, Joaquin Phoenix, and Puss in Boots, is fighting to protect his job in the era of AI: "I feel threatened even though my voice hasn't been replaced by AI yet" (Reuter). At the same time, this does not mean that artistic integrity is necessarily weakened whenever AI comes into play. In some contexts, AI may open aesthetic possibilities by allowing filmmakers to visualize environments that would otherwise be financially impossible. The key point is whether human judgment is maintained, and when it is, AI can add a new layer of artistic experimentation instead of threatening it. Therefore, the economic impact of AI must be understood with a complex, comprehensive viewpoint.

Alongside the colossal economic upturn that they bring, AI tools allow the democratization of technology for indie filmmakers. Indie filmmakers are independent filmmakers who often lack the technology, money, or infrastructure to create large-scale productions. However, AI can change this drastically. Indie creators can now access tools like Staircase Studio or Wonder to generate high-quality visual effects without the need for dramatic budgets. As such, Xavier Collins, Co-founder of Wonder, claims that "the power to craft and create visually striking stories is being rapidly democratized through technology... unlock[ing] new avenues of creativity and empowering [filmmakers] to do more with less" (The Australian). This directly assuages loss of authentic creativity because numerous filmmakers are now enabled to make higher-quality films in terms of VFX, sound editing, virtual production, and other ways in which AI can assist. Furthermore, according to Netflix co-chief executive Ted Sarandos, "AI represents an incredible opportunity to help creators make films and series better, not just cheaper. So this is real people doing real work with better tools" (Bonifield, 2025). Likewise, Academy Award-winning director James Cameron claims that "AI can be helpful because it can fill in some of those detail levels and allow us as artists to stay at a higher level"



(Perkel, 2025). That is, with the right balance of work distribution among human workers and AI, AI can become an extremely valuable tool that entails numerous benefits without threatening jobs.

These projections are meaningful because they indicate where investment is likely to flow. Investment is flowing into generative visual effects and personalized content systems for streaming platforms. That is, the first and largest stakeholders to benefit are likely to be major studios that have the resources to develop these tools and utilize them most efficiently. Although independent creators may still benefit from lower-cost access to certain capabilities, their gains are more likely to be creative and operational than structural. In other words, AI may widen participation in content creation without equally redistributing profit or market power.

Conclusion

So, what can we expect in the future? First, a significant number of jobs will be lost. These occupations include video editors, VFX artists, colorists, sound designers, storyboard artists, and even some screenwriters (Medium). Accordingly, appropriate measures must be implemented to mitigate job losses and displacement caused by AI. This can look like re-skilling and up-skilling programs to train creative professionals in AI-assisted tools so they can stay competitive (Cisco). Another method can be to develop union protections and regulations by strengthening labor contracts and pushing for ethical AI use (Reuters). While there are many ways to tackle the problem, cooperation between workers and companies will always be essential: without it, the industry's workforce may face significant consequences. There must also be a focus in ensuring that AI does not replace, but rather augment, human work. This can help minimize not only job loss but also loss of artistic integrity and creative ownership issues while bringing numerous exclusive benefits. At the end of the day, though, AI in the film industry is too recent: the number of relevant data and case studies is far too limited, making the future of AI mostly, if not entirely, unpredictable. Therefore, implementing strict measures to prevent the potential of AI from causing any sort of harm seems more important than ever.

References

AI in film market: News and forecast. (2025). *Scoop by Market.us*. <https://scoop.market.us/ai-in-film-market-news/>

AI in the workforce: Cisco calls for reskilling as 92% of roles evolve. (2024). *Cisco Newsroom*. <https://newsroom.cisco.com/c/r/newsroom/en/us/a/y2024/m07/ai-and-the-workforce-industry-report-calls-for-reskilling-and-upskilling-as-92-percent-of-technology-roles-evolve.html>

Business: Staircase Studio turns Hollywood's AI anxiety into opportunity. (2025, April 1). *New York Post*. <https://nypost.com/2025/04/01/business/staircase-studio-ai-is-turning-hollywoods-artificial-intelligence-anxiety-into-opportunity/>

Dimension Market Research: Generative AI in movies market. *Dimension Market Research*. <https://dimensionmarketresearch.com/report/generative-ai-in-movies-market/>

Exploring the impact of AI on film production in 2024. *Medium*. <https://medium.com/%40channelasaservice/exploring-the-impact-of-ai-on-film-production-in-2024-f02da745af00>



Generative AI is replacing 200,000 workers in Hollywood. *Plain English AI*.

<https://ai.plainenglish.io/hollywood-replaces-200-000-workers-with-ai-studios-stay-silent-as-jobs-vanish-4bf1f1ee19ee>

Hollywood actors union ratifies contract after strike. (2023, December 6). *Reuters*.

<https://www.reuters.com/business/media-telecom/hollywood-actors-union-ratifies-three-year-contract-after-strike-2023-12-06/>

Hollywood beckons as Blackbird backs AI filmmaker via \$47M raise. *The Australian*.

<https://www.theaustralian.com.au/business/dataroom/hollywood-beckons-as-blackbird-backs-ai-filmmaker-via-47m-raise/news-story/2822a323b3e24f850be0502a09521e5d>

James Cameron predicts how AI will cut production costs in half. *MovieGuide*.

<https://www.movieguide.org/news-articles/james-cameron-predicts-how-ai-will-cut-production-costs-in-half.html>

James Cameron says AI can cut costs, but doubts it can create emotionally resonant stories. (2025).

Variety. <https://variety.com/2025/film/news/james-cameron-blockbuster-movies-ai-cut-costs-1236365081/>

Marvel uses AI to create intro sequence for Secret Invasion. *Reddit*.

https://www.reddit.com/r/ArtistHate/comments/14f4o15/marvel_uses_ai_to_create_intro_sequence_for/

Morgan Stanley: AI in media and entertainment – benefits and risks. *Morgan Stanley*.

<https://www.morganstanley.com/insights/articles/ai-in-media-entertainment-benefits-and-risks>

Netflix uses generative AI in show for first time: El Eternauta. (2025, July 18). *The Guardian*.

<https://www.theguardian.com/media/2025/jul/18/netflix-uses-generative-ai-in-show-for-first-time-el-eternauta>

Number Analytics: Economics of virtual production. *Number Analytics*.

<https://www.numberanalytics.com/blog/economics-of-virtual-production>

Perkel, K. (2025). James Cameron on AI's role in future filmmaking. *MovieGuide*.

<https://www.movieguide.org/news-articles/james-cameron-predicts-how-ai-will-cut-production-costs-in-half.html>

Pineau, E., Murray, M., & Chmielewski, D. (2025, July 30). Voice actors push back as AI threatens

dubbing industry. *Reuters*. <https://www.reuters.com/business/media-telecom/voice-actors-push-back-ai-threatens-dubbing-industry-2025-07-30/>

Rowan, J., & Benson, J. K. (2024, February 1). "Madu" trailer from Disney+ teases story of viral Nigerian

ballet student. *The Hollywood Reporter*. https://www.hollywoodreporter.com/movies/movie-news/madu-trailer-disney-ballet-student-1235812134/attachment/madu171420_042_80_04673763/

Ted Sarandos on AI in filmmaking: 'Better, not just cheaper.' (2025, June). *Business Insider*.

<https://www.businessinsider.com/netflix-ted-sarandos-ai-filmmaking-cut-costs-not-kill-creativity-2025-6>

The impact of generative AI on Hollywood and entertainment. *MIT Sloan Management Review*.

UK audiences want assistance, but not AI-generated content. (2026, February 25). *YouGov*.

<https://yougov.com/en-gb/articles/54161-ai-in-streaming-entertainment-uk-audiences-want-assistance-not-ai-generated-content>



<https://sloanreview.mit.edu/article/the-impact-of-generative-ai-on-hollywood-and-entertainment/>

You won't believe this movie was made with AI. *BGR*. <https://www.bgr.com/tech/you-wont-believe-this-movie-was-made-with-ai/>

Author's Bio

Kaydn Jung is a rising senior at Seoul Foreign School with plans to study filmmaking and the film industry in college. To date, he has directed and produced two short documentaries and remains interested in conversations surrounding AI use as a divisive tool for future film endeavors.



DAEWOO'S COLLAPSE AND GM'S RENEWAL: EMPLOYEE VOICE AND THE COUNSELING FUNCTION AS A MECHANISM OF CORPORATE GOVERNANCE

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Abstract

This paper explores how the counseling function, which is defined as organizational processes whereby employee issues and risk signals are raised and acted upon, can also act as a tool of corporate governance. Through a synthesis and examination of relevant literature on topics such as psychological safety, organizational silence, and Employee Assistance Programs (EAPs), this paper analyzes and compares two corporate giants (Daewoo and General Motors) and how they responded to employee voice before and during times of crisis. The cases show that the suppression of employee feedback can be destructive and lead to organizational failure, while embedding a structured feedback mechanism can have numerous positive benefits and boost company resilience. This paper concludes that the counseling function should be introduced and formalized within broader corporate governance frameworks because the system is an effective risk management tool.

Keywords

Employee Voice; Corporate Crisis; Employee Assistance Programs; Corporate Governance

Introduction

Corporate failures are often analyzed in terms of issues on the balance sheet: too much debt, falling sales, margin erosion, etc. However, research also shows that even before these issues emerge, there are often many employees who are aware of the trouble ahead. The failure of employees and upper management to heed these warning signs and bring attention to their existence before calamity strikes is a failure of organizational culture. It points to a breakdown in the psychological and communication infrastructure within the firm, which this paper terms the counseling function. The counseling function can essentially be defined as an integrated system of mechanisms within corporations that allow employee concerns, emerging risks, and other problems to be brought to the attention of senior management. The counseling function encompasses multiple components (employee voice mechanisms, whistleblowing, protected disclosures, EAPs etc.). When such a mechanism is absent or suppressed, organizations lose the ability to detect emerging threats early and respond accordingly. This paper concludes that the counseling function should be seen not just as a tool of employee welfare or wellness; rather, it should be understood as an essential component of corporate governance and risk amelioration. Literature on psychological safety, organizational silence, and the expansion of thinking on HR initiatives like Employee Assistance Programs together show how crucial it is to install an effective employee communication system within an organization (Edmondson, 2018; Morrison and Milliken, 2000; Attridge, 2019). Using these lenses, the internal counseling systems should be thought of as a tool of internal diagnostics. To illustrate this argument, this paper juxtaposes two large industrial firms that faced intense challenges: Daewoo, whose collapse in 1999 illustrated the dangers of an overly hierarchical organization that suppresses employee voice, and General Motors (GM), which faced its own cultural failure during the catastrophic Ignition Switch Crisis. GM was chosen as a contrasting case study because it is also a large conglomerate but, unlike in the case of Daewoo, it chose to respond to its own crisis of organizational silence through taking steps to institutionalize employee concern mechanisms. This provides a useful benchmark for counseling function based reforms in governance in action. Particular focus is given to Daewoo's case, as it is clear that the lack of a robust employee counseling or feedback function led to an environment where employee disquiet was equated with disloyalty, meaning effective early warning systems were muted. In contrasting and analyzing the paths of these two companies, this paper argues that the counseling function is a crucial element for organizational resilience and growth that needs to be formalized and acknowledged by organizations and policymakers.



The collapse of the Daewoo Group in 1999 is one of the best-known examples of corporate failure in modern South Korean corporate history. What makes Daewoo's implosion particularly notable is that it was an example of not only poor financial decision-making but also a deficient company culture that set the company on a path for ruin (Lee, 2003). In its analysis of Korea's string of corporate crises in the late nineties, the International Monetary Fund (IMF) was highly critical of Daewoo's excessive diversification, the opacity of its cross-debt guarantees, and poor internal controls, which led to moral hazard-like behavior and mismanagement (International Monetary Fund, 2000). These concerns were echoed by a Korea Development Institute report titled *The Effects of the Economic Crisis and Corporate Reform on Korean Groups* (Joh, 2002).

However, it was not just poor financial controls or management decisions that made Daewoo ripe for failure. Daewoo's internal culture was also characterized by authoritarianism and an excessive degree of centralization. Kim details how Daewoo's founder, Woo Choong Kim, "operated the conglomerate with total command, unchecked and unsupervised," running all major decisions through the Group Chairman's Office, which bypassed formal boards and shareholder oversight (Kim, 2008). This extreme hierarchical culture meant that corporate choices were insulated from employee feedback. In fact, any form of pushback by employees toward the decisions of upper management was met with hostility and suspicion. Dissent within the workplace was considered a sign of disloyalty. While hardly an aberration in Korea at the time, Daewoo was known for being a particularly doctrinaire and extreme employer (Jones, 2018).

This absence of internal feedback and conflict resolution mechanisms exacerbated problems within the company and created a "culture of silence" (Morrison and Milliken, 2000). For example, the outbreak of severe labor unrest at Daewoo Motor, which subsequently resulted in mass layoffs and extended strikes, can be seen as a manifestation of the inability and incapacity of the organization to mediate between the needs of workers and broader corporate sustainability (Kirk, 2001). What this literature suggests is that Daewoo's fall was not simply a casualty of the Asian Financial Crisis. The organization lacked the institutional culture and infrastructure to manage employee relations effectively, and this left it highly susceptible to endogenous shocks.

Human resource and organizational psychology literature define the counseling function as "an effective and preventive people management strategy for organizations to help employees better manage stress, personal issues, or work-related problems" (Navare, 2008). There are various ways to achieve this, including through mechanisms like internal counseling units, Employee Assistance Programs (EAPs), and supervisor referrals for more specialized help and care. What is important to note is that these programs have been evaluated and have been proven to improve overall workplace morale, lower absenteeism, and expand productivity (Robertson and Cooper, 2011; Attridge, 2019). EAPs have grown from a very basic tool of employee management and assistance into a strategic tool for promoting overall organizational health. EAPs are a voluntary and confidential service provided by some employers that help employees address employment, financial, caregiver, health, or relationship concerns. Mark Attridge extensively explored the efficacy of these programs and found that they have become "a valued partner for employers interested in advancing workplace mental health" (Attridge, 2019).

The importance of sincere engagement between management and employees is also noted as being crucial for overall organizational morale. When employees feel ignored or their concerns are sidelined, their work satisfaction falls (Bailey et al., 2015). In their paper on the importance of employee morale, Thangaraja et al. assert that their conclusion supports the idea of the "broader significance of addressing employee engagement and morale in promoting individual and organizational flourishing" (Thangaraja et al., 2024). This finding supports the conclusion that an effective counseling function, which enhances employee morale, will be well placed to improve the overall dynamism of an organization.

An organization made up of motivated employees with high morale will be very well suited to an environment where organizational learning and adaptation are required. Carroll makes the point that effective counseling and employee-management engagement change individual distress signals into a broader tool for assessing organizational health (Carroll, 1996). Within dynamic environments (for



example, during periods of economic tumult or organizational restructuring), the counseling function can serve the role of an emotional anchor for employees and an information tool for upper management. The literature collectively emphasizes how the counseling functions operate at the intersection of employee well-being and organizational intelligence. These systems form a vital communication bridge through which current emotional realities become strategic insight. When embedded effectively, counseling and engagement allow organizations to recognize distress early, adapt to change, and sustain performance under pressure. Thus, the counseling function emerges not merely as a welfare measure but as an essential component of adaptive corporate governance and long-term organizational stability.

A final area of the literature needs to be explored: the concepts of psychological safety and organizational silence (Edmondson, 2018; Morrison and Milliken, 2000). Psychological safety occurs when people feel that the environment they are in is one that values their feedback. Crucially, within this zone of psychological safety, people feel secure enough to communicate their concerns and unhappiness or admit certain failures without worries of retaliation or punishment. On the other hand, organizational silence occurs when the environment within an organization suppresses agency and communication because of a real or perceived fear of retribution; such an organization has an inferior potential to learn and adapt.

Morrison and Milliken describe elements such as hierarchical distance, punitive leadership, and weak communication channels as important drivers of such a culture of silence. In contrast, Edmondson shows that organizations that actively encourage open communication outperform their rigidly hierarchical peers in times of crisis, where trust and problem-solving are sorely needed. When combined, these theories suggest that counseling systems have an important role to play in institutionalizing psychological safety and providing methods for employee voices to be heard.

Methods

This review employed a systematic search across multiple academic and non-academic sources to capture a varied overview of organizational silence, psychological safety, counseling functions, and corporate failure. Searches were conducted using JSTOR, Web of Science, Google Scholar, and ProQuest. Additional targeted searches were done within institutional repositories such as the IMF, OECD, and Korea Development Institute. Keywords included “organizational silence,” “psychological safety,” “employee voice,” “counseling function,” “corporate governance,” “Daewoo collapse,” and “GM ignition switch.” Due to the nature of the research question, the review incorporated peer-reviewed scholarship, industry analyses, legal investigations (e.g., the Valukas Report), corporate disclosures, and reputable journalistic accounts. Inclusion criteria required that each source provide either (1) empirical or theoretical insight into organizational communication systems, or (2) credible documentation of governance and cultural failures in large firms. Sources with unverifiable claims or lacking analytical value were excluded. Data from each source were extracted into a structured table capturing publication details, methodological approach (where applicable), key findings, and relevance to the counseling function framework. A thematic narrative synthesis was used to integrate insights across academic and grey literature. Quality assessment focused on transparency of evidence, methodological rigor (for academic sources), and institutional credibility (for reports and investigations).

Results

The trajectories of Daewoo and General Motors vividly illustrate the importance of a communication infrastructure within a company facing crisis. This section presents the key findings from each case through the lens of the counseling function framework established above, and considers the implications for governance and policy. This can often be the difference between an organization collapsing because of crisis or a transformational moment of positive growth. In the case of Daewoo, the severe problems associated with hierarchical opacity and a lack of a robust employee counseling function invited disaster by hiding the warning signs of financial danger. At GM, by aggressively incorporating the counseling function into its response to a crisis, the company reframed it into an opportunity for learning. By reframing internal dialogue between employees and management, the company changed its culture from reactive compliance to proactive problem-solving. Both cases suggest that the counseling function should be at the very core of risk governance and corporate ethics. It is then paramount for organizational culture and sustainability that the counseling function should be considered a vital



element of organizational intelligence. The boards of the company and upper-level management should consider the employee voice systems like psychological safety initiatives, various types of employee ombudsmen, labor unions, etc., as dynamic information systems that feed information from those working at the coal face of the organization. A useful analogy would be financial statements, which offer quantitative information about the state of the business; information from the counseling function would offer qualitative information on the state of the business.

This type of culture will not just emerge: it needs to be embraced by management as more than mere rhetorical acknowledgement. GM's evolution showed how the company took very concrete steps to change the culture of the organization and raise employee voice. Particular emphasis was placed on protecting those raising concerns that management or superiors might find uncomfortable. Managers need to be trained to not just listen but also interpret and act when issues are raised. This means there needs to be metrics created that will allow for the quantification, for example, the elevation of employee voice and subsequent action. All line managers should be assessed as part of their incentive schemes on how readily their subordinates were to raise concerns and how effectively they took action to ameliorate these concerns.

At the policy level, an evolved counseling function needs to be elevated and codified in governance frameworks and regulations. Policymakers and regulators should mandate that large corporations have procedures and processes in place that will maintain and support independent internal employee voice. In South Korea, for example, this could be integrated into the Korea Institute of Corporate Governance and Sustainability Code of Best Practices. In the broader OECD, the counseling function could be formalized as part of existing ESG governance indicators. Governments and the various industry associations can further entrench this model by offering certifications or incentive programs for companies that deeply embed the counseling function within their organizational culture and management structure. These schemes could operate in a manner similar to environmental certificates and show investors and consumers that the firm's internal culture is adaptive, open, and resilient. Protections for whistleblowers need to be further expanded and strengthened. These channels of employee disquiet need to be encouraged because they serve a vital early warning function. Firms that have implemented policies and procedures that protect this vital employee voice mechanism should be recognized and rewarded.

Embedding psychological safety and feedback infrastructure into governance codes could serve as a preventative tool that helps lower risk to corporates. In institutionalizing corporate emotional intelligence, policymakers, managers, and boards will ensure firms remain highly attuned to distress signals emerging from their own workforces. While the analysis draws specifically on Daewoo and GM, the organizational dynamics identified therein, regarding hierarchical opacity, a suppression of psychological safety, and poor to nonexistent communication channels to management, are not unique to these firms or the countries they were based in. This pattern exists across a wide range of sectors and jurisdictions, suggesting that the counseling function's role as a governance mechanism has applicability well beyond the two cases examined here.

Discussion

The discussion that follows is organized in the following way: a detailed examination of Daewoo's hierarchical culture and its contribution to organizational collapse is examined; an analysis of GM's post-crisis cultural transformation is unpacked; and, a consideration of the broader policy implications of formalizing the counseling function within corporate governance frameworks is discussed. When the Daewoo Group imploded in 1999, it sent shockwaves across the Asia-Pacific. Daewoo was the second (or third, depending on the measure) largest chaebol (the Korean name given to the mega-conglomerates like Samsung, LG, Hyundai, etc.) in Korea just before the Asian Financial Crisis. When the company finally went under, it had debts of between US\$50-\$80bn (Dowling, 2007). It is difficult to emphasize what an enormous impact this had on the Korean economy at the time.

Daewoo: A hierarchical corporate culture and the road to collapse

Daewoo was founded in 1967 and, like many of its *chaebol* peers, it initially focused on a relatively narrow area of business: textile exports. Over time, the company grew and so did the list of products it produced: machine tools, cars, semiconductors, petrochemicals, construction equipment, etc. This



expansion meant that at its peak, the company employed approximately 320,000 people across 590 subsidiaries (Kim, 2008). The company was hardly the only chaebol to founder in the wake of the Asian Financial Crisis; however, it was definitely the largest, by many orders of magnitude. The Korean government at the time was confident that the so-called big five chaebol would be able to effectively weather the storm (Kirk, 2001). Much has been written about Daewoo's poor financial controls and excessive debt levels; however, less has been written about the lack of a comprehensive and well-directed employee counseling function, which may have averted the calamity the company faced by providing advanced warning.

It could be argued that Daewoo's failure was hardcoded into management practices and broader corporate culture. Like many of its peers, its founder and his extended family had an extreme form of control and authority within the company. This extreme control was an asset during its time of rapid expansion because decisions were quickly made, and the company had a relentless ability to pursue its objectives. However, this self-same centralized control also birthed the structural conditions for organizational silence and the antithesis of psychological safety. By eliminating dissent and concentrating so much power and authority in the hands of Chairman Woo Choong Kim, the company created conditions ripe for more moral hazard.

Edmondson's idea of psychological safety within the workplace was very much absent within Daewoo (Edmondson, 2018). There was a very real fear of some form of reprisal should an employee raise concerns or push back against the dictates of upper management. The Group Chairman's Office oversaw all major appointments and dismissals and ensured that promotion within the company was connected to loyalty (Kim, 2008). The result of this was that all employees understood that objecting and raising concerns in a way that wasn't considered "productive" could be career-ending. Donald Sull argues that this quasi-dictatorial style of leadership was not ancillary but embedded at the very core of Daewoo's identity: "Kim's personal values—relentless perseverance and fearless risk taking—permeated Daewoo's corporate culture" (Sull, 2005). The company's unofficial motto, "We do it now," perfectly encapsulates a culture that values rapid application and obedience over deliberation and hesitation. This ambitious, almost reckless approach to growth at the expense of a feedback culture is supported by Cho et al., who describe a situation of a "dynamic collectivism" in these Korean mega corporations (Cho et al., 2012). This condition is loosely defined as an ideological blend of hierarchical loyalty/group conformity that "value orientation toward obedience to the high rank person (e.g., own boss) ...[and] towards following common opinions of colleagues" (Cho et al., 2012). This culture both rewarded alignment with a superior's vision and penalized perceived divergence. In Daewoo's case, such a culture meant that even as financial risks grew, few within the organization felt they could take action, as organizational silence ruled.

The paucity of embedded feedback and counseling mechanisms within the company resulted in warning signs being ignored or suppressed. There were undoubtedly employees who could see the burgeoning catastrophe beginning to emerge, but were afraid to raise their voices. In hindsight, it seems obvious how the company's reckless debt accumulation or convoluted accounting practices created an arena where there was a lack of psychological security and organizational silence. Daewoo's downfall, therefore, was not merely an accounting failure but a profound communication failure. Kim demonstrates this by noting that Daewoo's internal governance often bypassed formal board structures, with "representative directors and board members appointed directly through the Chairman's Office weeks before shareholder meetings that merely rubber-stamped approval" (Kim, 2008). And, more worryingly, "The concentration of power in the Chairman's Office therefore allowed Kim to order executives to commit the accounting fraud." This type of corporate structure meant dialogue could only flow in one direction: downward, as imperatives. Upward communication from lower-level employees, what Edmondson would call "voice behavior" (where employees proactively offer actionable feedback), was virtually non-existent.

Labor relations within Daewoo were also poor, and unions were regarded with suspicion, not as constructive partners. Between 1995 and 1998, a number of extended strikes rocked Daewoo-affiliated companies. Some of the grievances raised by the unions concerned corporate governance within the company. However, Daewoo refused to make any concessions on this front (Kim, 2008). These strikes were often met with layoffs, blacklisting, and arrest. Kim explains how unions and employees were frozen out of important decisions, and their ability to access information was severely limited: "Under



the hierarchical decision-making structure, employees rarely challenged their superiors. A strong culture of group loyalty prevailed. No one raised issues or engaged in whistle-blowing” (Kim, 2008). Without robust union feedback and a weak to non-existent counseling function, Daewoo had no mechanism for emotional regulation or adaptive response. As the company lurched from one crisis to the next, it entered what Sull describes as “active inertia,” whereby it responded to crisis with more of the same behavior that originally caused it (Sull, 2005).

The corporate makeup of Daewoo meant that the fundamental HR functions were subordinated to the whims of the executive. The personnel division was essentially a vehicle of administration, prioritizing employee compliance and control over welfare and communication. Within Daewoo, there is no evidence of any institutional equivalent to the modern EAP, internal ombudsman, or confidential whistleblowing channel through which concerns could be raised and mediated. It is fair to say that the “counseling” realm of HR (listening, mediation, stress management, etc.) was basically non-existent. This meant that when anxiety, overwork, and ethical concerns surfaced, they remained private and only manifested themselves during strikes or quitting. This vacuum meant that management interpreted silence as agreement and acquiescence rather than distress, compounding moral hazard and eroding the organization’s adaptive capacity.

The important role that the counseling function plays in organizations that are facing a series of crises is well illustrated by what occurred at Daewoo. Far from being a peripheral welfare tool, the counseling function could have offered a path to raw intelligence on the state of the organization and the emotional state of its employees. If Daewoo had possessed such a system, be it in the form of internal counseling units, employee assistance programs, or confidential reporting lines, the warning lights of overextension may have been heeded earlier, and calamity averted.

General Motors: Turning crisis into learning

There are a variety of alternative paths that Daewoo could have pursued when the first tremors of crisis were felt at the company. Instead, Daewoo’s top management, and particularly its Chairman Woo Choong Kim, decided to double down on the existing company culture. To what extent reforming Daewoo’s culture would have made a difference in the company’s collapse will always be an open question. However, what is true is that changing a company’s culture so that there are ways for employees to sound the alarm when things go wrong is undoubtedly beneficial. At this point, it is worth examining a similar company, also embroiled in crisis, that chose to embrace the counseling function instead of the status quo and, in so doing, became more dynamic as a result.

When General Motors filed for bankruptcy in 2009, it was faced with both financial calamity and an organizational culture that was unfit for renewal and growth. Bill Vlasic describes in his book, *Once upon a car: the fall and resurrection of America's big three auto makers - GM, Ford, and Chrysler*, an organization that was beset with problems as a result of rigid hierarchies, institutional complacency, and erratic internal communication (Vlasic, 2011). Additionally, the New York Times describes how, historically, GM was a place that “adhered to a strict code of conformity and predictability” (Vlasic, 2011). The sheer brokenness of the company’s culture was probably best illustrated by the 2014 Ignition-Switch Crisis. In an external investigation led by former U.S. attorney Anton Valukas, the investigators described how safety issues were repeatedly deferred, rather than escalated; how there was a reluctance to raise bad news; and how cost-cutting pressures from upper management led to a decline in product safety and quality (NAFUSA, 2014).

Just like the financial and debt disaster that gradually grew at Daewoo in the 1990s, the ignition switch defect was not something that just suddenly occurred. Rather, it was as a result of a culture at GM that, in a multitude of ways, both suppressed broader knowledge of the issue and action to fix it. In Valukas’ report, it is clear that parts of GM knew of the issue as early as 2002 (although the severity of the issue was not known). A timeline of the problem shows multiple times when the organization had the chance to take action and change course, but either could not or would not. One entry, from around late 2005, is particularly chilling: “After Numerous Reports of Moving Stalls, Engineering Work to Resolve the Problem, Multiple Committee Meetings, and a Brief Investigation” by GM’s Safety Investigators (NAFUSA, 2014). What follows is a string of missed opportunities to correct the issue. Reports indicated that at least 153 deaths could be linked to the problem, and 12.8 million cars needed to be recalled to fix the issue (Klayman, 2014; Fletcher, 2014).



The report points explicitly to a cultural issue within the company that allowed the issue to fester. Witnesses who were interviewed stated that there “was a resistance or reluctance to raise issues or concerns in GM culture” and that “if an employee tried to raise a safety issue five years ago, the employee would get pushback.” The report also found that “GM participants’ rate of reporting misconduct they observed was below the benchmark developed by the Compliance and Ethics Leadership Council.” There were also reports of employees who had a “fear of retaliation.” Some witnesses also stated that there were times they were discouraged from reporting safety issues and were explicitly told by supervisors, “never put anything above the company” and “never put the company at risk” (NAFUSA, 2014). This culture of silence and lack of psychological safety meant that GM could not take effective action to remedy the issue until it was too late.

After the recall, investigation, and subsequent scandal, GM explicitly embraced a cultural shift that would dramatically shift the psychological fundamentals of the company in a way that would elevate employee feedback and embed the counseling function as a core system in GM’s corporate governance regime. The company used the counseling function as more than an employee welfare tool and more as a mechanism for organizational learning and awareness. This was an acknowledgement that a technical fix alone would not be sufficient.

There were a number of initiatives that were implemented through the counseling function to bring this to fruition. Firstly, there was the *Speak Up for Safety* campaign, which provided a channel for employees to report issues (General Motors Company, 2014). This wasn’t just a grievance line but was aimed at shifting how employees felt about disclosure—it was an honorable and worthy thing to do. This went directly counter to the “betrayal” narrative of before and provided that all-important psychological safety. People were also publicly recognized and praised when they raised issues to demonstrate this. This effort was given legal and institutional clout through the “Global Speak-Up! Non-Retaliation Policy,” which was promulgated to create “a culture where everyone feels free to share concerns regarding the operation of the business.” Essentially, this policy assured those who wanted to speak up that they would not have to fear any form of retaliation for taking a principled stand on an issue they felt was a danger to the business (General Motors Company, 2025). There was also an express approach of upper management listening to the concerns of employees, particularly in terms of safety. What emerged from all these changes was an organization that used the counseling function as a tool of institutional learning.

GM’s institutional evolution after the Ignition Crisis demonstrates how the counseling function can be reworked and reimagined as a tool of learning and growth. Originally intended as simply a mechanism of individual welfare, this vital HR function was reconfigured as a communication and reflection tool. The introduction of formal voice mechanisms, such as the *Speak Up for Safety* program and the *Global Speak-Up Non-Retaliation Policy*, institutionalized feedback as an integral part of the firm’s governance architecture rather than an optional HR add-on.

This model illustrates an evolved counseling function: one that changes vertical hierarchies into systems of dialogue and reflection, driven by the idea of anticipatory correction. In short, GM embedded structured forums for dialogue and psychological safety into management practice. By creating protected spaces for raising doubts and concerns, GM converted what had been silence-induced risk into actionable business growth intelligence.

Conclusion

The corporate trials of GM and Daewoo show how the seeds of failure often germinate even before an issue appears on the balance sheet or as a public scandal. A failure to heed these warnings points to a failure in internal communication and the psychology within the organization. Daewoo’s collapse showed how an absence of psychological safety, in concert with an intensely hierarchical culture, can potentially suppress early warnings and create the conditions for catastrophic breakdown. The design of the organization, where dissent and questioning the imperatives of upper management were equated with disloyalty, ultimately disabled the organization’s warning system and left the company susceptible to endogenous shocks (like the Asian Financial Crisis). The creation of such a culture leaves these organizations badly exposed and predisposed toward crisis because they cannot perceive a crisis until it is too late. GM illustrates a firm that decided to move away from such an approach of avoiding difficult conversations and fully internalize the counseling function as a tool of organizational learning. By



protecting employee voice, the company indicated that dissent and employee psychological well-being were assets that would help the company grow and prosper. Such an approach changed the internal communication system by encouraging transparency, surfacing risk, and enabling adaptive management. When examined holistically, the cases of Daewoo and GM underscore the core claim of this paper: that the counseling function is not just a tool of employee welfare but a central element of corporate governance and sustainability. Organizations and policymakers need to formalize and strengthen the systems that will allow such a culture to deeply take root. In short, the counseling function must be considered as a vital tool of management in complex firms that are facing challenging times.



References

- Attridge, M. (2019). A global perspective on promoting workplace mental health and the role of employee assistance programs. *American Journal of Health Promotion*, 33(4_suppl), 1S–6S. <https://doi.org/10.1177/0890117119838101c>
- Bailey, C., Madden, A., Alfes, K., Fletcher, L., Robinson, D., Holmes, J., Buzzeo, J., & Currie, G. (2015). Engagement and morale. In *Evaluating the evidence on employee engagement and its potential benefits to NHS staff: A narrative synthesis of the literature*. NIHR Journals Library. <https://www.ncbi.nlm.nih.gov/books/NBK299339/>
- Carroll, M. (1996). *Workplace counselling: A systematic approach to employee care*. SAGE Publications. <https://doi.org/10.4135/9781446216927>
- Cho, Y.-H., Yu, G.-C., Joo, M. K., & Rowley, C. (2012). *Do corporate cultures change over time? Evidence from South Korea*. Cass Business School, City University London. https://www.citystgeorges.ac.uk/_data/assets/pdf_file/0008/365417/cass-knowledge-chaebol-south-korea-culture-change.pdf
- Dowling, J. M. (2007). *Future perspectives on the economic development of Asia: Advanced research in Asian economic studies: Volume 5*. World Scientific. <https://doi.org/10.1142/6417>
- Edmondson, A. C. (2018). *The fearless organization: Creating psychological safety in the workplace for learning, innovation, and growth*. John Wiley & Sons.
- Fletcher, M. A. (2014, May 16). General Motors recalls another 2.7 million vehicles. *The Washington Post*. https://www.washingtonpost.com/business/economy/general-motors-recalls-another-27-million-vehicles/2014/05/15/f8bce616-dc40-11e3-bda1-9b46b2066796_story.html
- General Motors Company. (2014, April 10). GM creates speak up for safety program for employees [Press release]. MarketScreener. <https://www.marketscreener.com/quote/stock/GENERAL-MOTORS-COMPANY-6873535/news/General-Motors-GM-Creates-Speak-Up-For-Safety-Program-for-Employees-18241004/>
- General Motors Company. (2025). *2024 Annual Report* [Annual report] (p. 120). General Motors Company. <https://investor.gm.com/static-files/e86cba95-5077-4097-bf21-b3de40126ca8>
- International Monetary Fund. (2000). *Republic of Korea: Economic and policy developments* (Country Report No. 00/11). International Monetary Fund. <https://doi.org/10.5089/9781451822175.002>
- Joh, S. W. (2002). *The effects of the economic crisis and corporate reform on Korean groups*. Korea Development Institute. <https://doi.org/10.22740/kdi.ps.2002.10>
- Jones, R. S. (2018). *Reforming the large business groups to promote productivity and inclusion in Korea* (OECD Economics Department Working Papers, No. 1519). OECD Publishing. <https://doi.org/10.1787/9e9052b5-en>
- Kim, J. (2008). A forensic study of Daewoo's corporate governance: Does responsibility for the meltdown solely lie with the chaebol and Korea? *Northwestern Journal of International Law & Business*, 28(2), 273.
- Kirk, D. (2001, February 17). Big job cut at Daewoo Motor prompts protests by workers. *The New York Times*. <https://www.nytimes.com/2001/02/17/business/international-business-big-job-cut-at-daewoo-motor-prompts-protests-by-workers.html>
- Kirk, D. (1999, July 22). Group's collapse would be a setback for South Korean economy: For Daewoo, a struggle for survival. *The New York Times*. <https://www.nytimes.com/1999/07/22/business/worldbusiness/IHT-groups-collapse-would-be-a-setback-for-south.html>
- Klayman, B. (2014, September 29). Deaths linked to GM ignition-switch defect rise to 23. *Reuters*. <https://www.reuters.com/article/business/deaths-linked-to-gm-ignition-switch-defect-rise-to-23-idUSKCN0HO1F2/>
- Lee, D. G. (2003). The restructuring of Daewoo. In E. Kim, S. Haggard, & W. Lim (Eds.), *Economic crisis and corporate restructuring in Korea: Reforming the chaebol* (pp. 150–180). Cambridge University Press. <https://doi.org/10.1017/CBO9781139085083.009>
- Morrison, E. W., & Milliken, F. J. (2000). Organizational silence: A barrier to change and development in a pluralistic world. *The Academy of Management Review*, 25(4), 706–725. <https://doi.org/10.2307/259200>
- NAFUSA. (2014, June 11). *Valukas issues GM internal investigation report*. National Association of Former United States Attorneys. <https://www.nafusa.org/2014/06/valukas-issues-gm-internal-investigation-report/>
- Navare, S. (2008). Counseling at work place: A proactive human resource initiative. *Indian Journal of*



- Occupational and Environmental Medicine*, 12(1), 1–2. <https://doi.org/10.4103/0019-5278.40807>
- Robertson, I., & Cooper, C. (2011). Well-being, productivity and happiness at work. In *Well-being: Productivity and happiness at work* (p. 224). Palgrave Macmillan. <https://doi.org/10.1057/9780230306738>
- Sull, D. (2005). Why good companies go bad. *Harvard Business Review*, 77, 42–48, 50.
- Thangaraja, G., Munusamy, P., Macwan, A. J., Patil-Nikam, A. M., Nalini, V., & Rai, R. (2024). Employee engagement, morale, and organizational performance: A systematic review. *Educational Administration: Theory and Practice*, 30(4). <https://doi.org/10.53555/kuey.v30i4.2524>
- Vlasic, B. (2011). *Once upon a car: The fall and resurrection of America's big three automakers—GM, Ford, and Chrysler*. HarperCollins. http://archive.org/details/onceuponcarfallr0000vlas_z5s9



THE LIMITATIONS OF UNCLOS AND THE MOVE TOWARDS A HYBRID MODEL: CASE STUDIES IN EAST ASIAN MARITIME DISPUTES

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Abstract

The United Nations Convention on the Law of the Sea (UNCLOS) was created in the early 1980s to prevent the oceans from becoming an irreversible case of the tragedy of the commons. It was thought that a global agreement on the management and use of the oceans would slow and possibly reverse existing damage. This paper reviews the literature to examine the limitations of global governance frameworks and uses case studies of China's construction of artificial islands in the South China Sea, the Philippines' arbitration proceedings against China under UNCLOS, and Japan's classification of Okinotorishima under Article 121 to show that states across the compliance spectrum have interpreted the convention selectively. The analysis argues that a hybrid approach prioritizing agreements adapted to the unique demands and cultures of smaller regions within the broader global framework, while using global agreements for coordination and knowledge-sharing, offers the most promising path forward for ocean governance.

Keywords

International law; law of the sea; UNCLOS; artificial islands; East Asia; South China Sea

Introduction

Adopted in 1982, the United Nations Convention on the Law of the Sea (UNCLOS) aimed to establish "rules for the allocation of States' rights and jurisdiction in maritime spaces, the peaceful use of the oceans and the management of their resources" (International Maritime Organization, n.d.). However, this global regulation has failed to effectively manage the complex and dynamic nature of human activity and its interaction with the oceans. Arvid Pardo, the diplomat known as the "father" of UNCLOS, characterized its failure with the rebuke that "All that is left of the common heritage of mankind is a few fish and a little seaweed" (Standing, 2022). The threats to the oceans and the life they contain are numerous and include, but are not limited to, overfishing, mining, pollution, warming, declining biodiversity, acidification, deoxygenation, and noise. Given the apparent failure of UNCLOS to prevent these threats from developing and how the threats differ from region to region, some have argued for abandoning efforts for global regulation and redirecting focus on the creation of regional agreements, which, it is argued, are easier to create and enforce. However, regional agreements cannot effectively address the global nature of the threats to the oceans. Instead, a hybrid model that uses global agreements as a form of general coordination and more precise, narrowly defined regional agreements to address specific threats will best facilitate the attempts to halt and possibly reverse the damage being done to the oceans. Case studies of China's construction of artificial islands, the Philippines' experience with UNCLOS arbitration, and Japan's classification of disputed maritime features will be used to show that the hybrid model offers the most effective approach to complex governance issues requiring regional cooperation underpinned by international standards.

Methods



This paper uses a qualitative literature review and comparative case-study method to evaluate whether governance frameworks have been effective for the management of the world's oceans. In addition to searching academic databases, the author also searched international legal documents and policy publications. Articles were selected that contained the keywords "Ocean Governance," "UNCLOS," "Marine Law," and "International Environmental Compliance" and were ranked according to relevance. Articles selected included both peer-reviewed and non-peer-reviewed (also referred to as gray) literature to account for all the various aspects involved, such as reports by the United Nations and policy-based think tank reports. As part of this research, the author also conducted a comparative analysis of China's maritime behavior in the South China Sea and Yellow Sea, the Philippines' use of UNCLOS arbitration mechanisms, and Japan's classification of disputed maritime features, in order to demonstrate how state practice produces selective interpretations of international law. The large volume of documentation available on these cases provided sufficient data to conduct an in-depth examination of the areas where inconsistencies and ambiguity in the case record arise.

Results And Discussion

Global Governance and Its Challenges

The major global governance framework of the oceans is UNCLOS. It is "widely viewed as a 'constitutive instrument that provides a legal framework that is being filled in, rounded out and complemented by existing and subsequently enacted international agreements and customary international law'" (Center for International Law, n.d.). It is a "framework within which a mosaic of different legal and non-legal institutions rests" including "international and national governance, in which governments and various public bodies are the primary actors" but includes "private governance initiatives led by companies and other non-state actors such as environmental organizations" (Pretlove & Blasiak, 2018). UNCLOS "contains relatively few detailed or precise obligations" and "leaves more detailed rules on issues such as shipping, fisheries and protection of the marine to subsequent agreements, of which there are many" (Churchill & Hartmann, 2021). UNCLOS has been described as "almost universally lauded for laying down laws and rules [whose] wide acceptance it is believed has greatly reduced the number, frequency and potential for inter-state conflicts that would otherwise have taken place" (Vanaik, 2020). This was achieved with agreement under UNCLOS that the area of the ocean 200 nautical miles from a State's coastline was an Exclusive Economic Zone (EEZ) for that State and gave the State "sovereign rights to explore and exploit in the seas, the seabed and subsoil" (Vanaik, 2020). Everything not included in the EEZs was described as the "common heritage of mankind," and the International Seabed Authority (ISA) was created to regulate the area not defined as part of an EEZ through "licenses and contracts with companies and governments" (Vanaik, 2020).

UNCLOS also created a dispute resolution mechanism, but fewer than 50 disputes have been heard compared to more than 600 at the World Trade Organization's equivalent mechanism, which was created at the same time (Serdy, 2021). The lack of use of the dispute resolution mechanism has been described as a sign of success as "it suggests that UNCLOS rules are for the most part clear and realistic enough not to generate disputes at all" (Serdy, 2021). However, as a form of international law, UNCLOS relies on consent and has no means to enforce decisions, and parties to the disputes often do not send representatives to attend the UNCLOS dispute resolution process (Serdy, 2021). Despite this claimed success, it has been found that UNCLOS currently "lacks the adaptability needed to respond to novel challenges such as climate change, deep-sea resource extraction, and geopolitical tensions" and even though "UNCLOS remains a foundational pillar for maritime law, there is an urgent need for reforms and supplementary agreements to ensure its relevance and effectiveness" (Capel, 2023). Although some argue that the weaknesses of UNCLOS are to some extent balanced by developments related to its adoption, such as EEZs, many criticize the inability of this type of global regulation to deal with significant challenges. For example, research shows widespread non-compliance with UNCLOS (Churchill, 2012). Furthermore, the world's major economic power, the United States, has not ratified UNCLOS due to "deep-seated, ideological concerns over maintaining commercial autonomy in the maritime domain" (Kraus, 2023). Although these problems are significant, the most immediate and dangerous challenge to global



governance of the oceans has been made by China.

China asserts historic rights within the nine-dash line over much of the South China Sea, a position that the 2016 arbitral tribunal found incompatible with UNCLOS where it exceeds maritime entitlements generated under the Convention (Mastro, 2021). UNCLOS has failed to create a consensus internationally on the freedom of navigation of military vessels. The US and Australia claim that “freedom of navigation of military vessels is a universally established and accepted practice enshrined in international law,” but Argentina, Brazil, India, Indonesia, Iran, Malaysia, the Maldives, Oman, Vietnam, and China argue they “have the right to limit navigation or exercise any control for security purposes in EEZs” (Mastro, 2021). China has also constructed artificial islands on contested reefs and rock formations in the South China Sea. Rather than generating EEZ entitlements through these structures—UNCLOS does not recognize artificial installations as EEZ-generating features—China has exploited the convention’s definitional ambiguity between natural islands, rocks, low-tide elevations, and artificial installations to create legal and factual control over disputed maritime space. An international tribunal found that UNCLOS prohibits the construction of artificial islands in the EEZ of another State, but failed to “provide clear guidance for determining the legitimacy of a state constructing an artificial island in international waters not within its own EEZ or an EEZ belonging to another state” (Kohl, 2018).

With regard to global warming and pollution, such as microplastics, there is confusion about whether UNCLOS creates obligations for States. UNCLOS Part XII Article 192 says “States have the obligation to protect and preserve the marine environment” (United Nations, 1982). Legal researchers are attempting to argue that this means UNCLOS State parties “may have a legal obligation to contribute to a fund that compensates countries for environmental harms caused by climate change” (Wam, 2024). Others argue that Article 192 could be used to regulate emissions that cause global warming (Agarwal & Agnihotri, 2022). Finally, some argue that “a future plastics treaty should be framed as a means of supporting the implementation of the requirements set out in UNCLOS” (Mendenhall, 2023).

Although UNCLOS has faced significant challenges since its ratification, governments and researchers have invested significant time and effort in creating a new global agreement with the aim of protecting “marine life in the ocean areas that lie beyond countries’ individual jurisdictions” (Pickerell & Swift, 2025). The Treaty for the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ) has been created under UNCLOS but will face the same issues of ratification, compliance, and enforcement (Pickerell & Swift, 2025). The binding agreement has been described as an “extraordinary diplomatic achievement,” but unresolved issues include “who will actually police” the newly created marine protected areas (MPAs), the lack of a dispute resolution system, and the level of financial resources made available for implementation (Patrick, 2023). Finally, the US signed the treaty under the Biden Administration, but the Trump Administration will not be ratifying it, creating the same fundamental weakness that exists for UNCLOS generally (Hughes, 2025).

The core challenge of any global agreement on protecting the oceans is that it will be vulnerable to international geopolitics. There is a general acceptance that in a multipolar globalized world, there is a need for “ordered rule and collective action,” and “global governance provides the needed orderliness and collective actions with processes and institutions that seek to manage pressing global problems” (Adewumi, 2021). However, these systems often have the unintended effect of merely creating new forms of “competition among states” (Adewumi, 2021). There is extensive evidence for using “ocean issues to compete and accrue political leverage” among African countries, in the Arctic, and in the South China Sea (Adewumi, 2021).

Regional Agreements and Their Effectiveness

Research on 263 multilateral environmental agreements between 1950 and 2017 has found that “regionally focused environmental agreements are two and a half times more likely to be ratified than globally focused environmental agreements” (Capel, 2023). Furthermore, one of the comparative strengths of regional agreements is that States have been found to be much more likely to contribute the significant resources needed to make change when an agreement to cooperate is regional and not global (Kahler, 2017). Regional agreements also benefit from the ability to “mobilize local knowledge more effectively” and create



competition with other regional agreements and global agreements that encourage “innovation and experimentation” (Kahler, 2017). Research shows that some of the criticisms of regionalism as opposed to globalism have also become outdated, as a “new regionalism” has emerged since the Cold War. Pre-Cold War regionalism has been described as “introverted and protectionist,” “exclusive in terms of membership,” and “state centered and state dominated” (Söderbaum & Hettne, 2006). In contrast, Post-Cold War regionalism can be defined as “extroverted, linked with globalization,” with “inclusive and open membership,” and involves “state, market, and civil society actors in many institutional forms” (Söderbaum & Hettne, 2006). However, one of the most successful examples of regional cooperation on the regulation of oceans has been the Convention for the Protection of the Mediterranean Sea Against Pollution (the Barcelona Convention), which was adopted in 1976, before the end of the Cold War. One of the strengths of the convention has been the participants’ willingness to update and develop the regulation efficiently to address emerging problems, something that global agreements such as UNCLOS struggle to achieve (Frantzi, 2008).

Another regional example of cooperation that has achieved significant successes is the Arctic Council. One of its strongest achievements has been the creation of the Arctic Climate Impact Assessment (ACIA). The ACIA focused on the narrow regional effects of climate change, and participant states funded the required research because they could see exactly how the money would be used and the results that would be expected. The specialized focus of the Arctic Council has meant that it has achieved “the development of a cooperative regime that has few if any equals” (Bloom, n.d.). The reason for the success of the Arctic Council has been identified as its focus on local problems with narrow expertise, which then informs general policy making: “the council has achieved considerable success in identifying emerging issues, framing them for consideration in policy venues and raising their visibility on the policy agenda” (Kankaanpää & Young, 2012).

Limitations of Regional Agreements

Although regional agreements have significant strengths, some argue that the “new regionalism” is opposed to the multilateralism of global agreements. At an international level, States have to balance their interests, but at a regional level, larger states can use their economic or military strength to shape agreements to empower themselves. Another weakness is the re-emergence of the pre-Cold War approach of exclusivity and introversion. This has been described as a “trend toward strengthening ties with friends and loosening them with non-friends” that “may reignite regional discrimination” (Ruta, 2023). The fundamental weakness of regional agreements is that regionalism without the anchor of multilateralism may be more exposed to the powerful forces of disintegration (Ruta, 2023).

Another significant weakness of regional agreements is that “international progress is limited by significant variation, with many regions failing to deliver effective environmental governance” (Newman, Mukherjee, & Hoole, 2024). Regional agreements in isolation fail to facilitate the sharing of knowledge and technology that has become an important part of global agreements such as UNCLOS and the new High Seas Treaty. For regional agreements to have the greatest impact, the use of global agreements and the dialogue and debate they encourage is required.

Despite the potential for regional agreements to act as catalysts for global agreements, there is a risk that negotiations at a regional level fail to lead to radical or ambitious change because the costs associated with the change will not be shared globally. For example, China, India, and the United States are the largest emitters of greenhouse gases, and reducing these emissions would require significant economic cost (Maizland & Fong, 2026). No government is likely to commit to the high costs of radical change if economic competitors in a different region are not agreeing to the same costs. For governments to commit high levels of investment to solving problems like microplastic pollution and biodiversity collapse in the oceans, global agreements are required, as regional agreements cannot coordinate the timing of such investments.

Regional agreements also face some of the same obstacles as global agreements. For example, compliance and enforcement remain challenges for any international agreement. States are more likely to have closer economic and cultural ties to their neighbors and, therefore, feel a sense of responsibility to enact change in their region. However, historic rivalries and grievances may also be amplified at a local



level, which would make establishing consensus challenging.

Case Study

The three cases below illustrate how different states have interpreted UNCLOS selectively: China by exploiting the convention's definitional ambiguities to create factual control while rejecting adverse rulings; the Philippines by successfully invoking UNCLOS arbitration yet finding the award unenforceable; and Japan by classifying disputed maritime features in ways that neighboring states contest as exceeding what Article 121 permits. Together they identify a structural problem: selective interpretation is not confined to states that openly defy the convention, but also characterizes states that formally accept its authority.

China

Although UNCLOS establishes rules for the governance of the seas through constructs such as exclusive economic zones, China has sought to use these rules to expand its international influence (Orford, 2021). China asserts historic rights within the nine-dash line over much of the South China Sea, a position the 2016 arbitral tribunal found incompatible with UNCLOS where it exceeds maritime entitlements generated under the Convention (Mastro, 2021). In the Yellow Sea, China has been "using so-called gray zone tactics to assert its claim over vast stretches of maritime territory – claims contested by several neighboring countries in the area" (Lee, 2025). By occupying contested reefs, dredging sand from the ocean floor, and constructing installations on rock formations, China exploits UNCLOS's definitional ambiguity between natural islands, low-tide elevations, rocks, and artificial structures to manufacture legal and factual control over disputed maritime space. UNCLOS does not recognize artificial installations as EEZ-generating features, yet the convention's imprecision on these distinctions has left sufficient room for China to contest any straightforward application of the rules against its activities. Regional neighbors dispute the claims, but China presents its conduct as asserting rights under international law.

To avoid this type of exploitation of generalized international rules, regional agreements negotiated by neighbors are required. Regional agreements that use international norms as a foundation and framework for specific local solutions are needed to prevent conflict over the application of international norms in regional contexts. The challenge of this approach is that the strongest regional powers may impose themselves on smaller neighbors, but this is a constant issue in all regional diplomatic negotiations, and smaller powers have the opportunity to cooperate against larger neighbors. In the case of China, South and North Korea, the Philippines, Taiwan, Japan, Malaysia, and Indonesia will have a strong interest in cooperating to negotiate regional agreements that prevent the use of the gray zone tactics that have emerged as a consequence of the gaps and differing interpretations of international law.

Regional negotiations will prevent China from using the defense that accusations from the West and the U.S. in particular are motivated by a desire to restrain China unjustly or by imperialistic goals (Doherty, 2019). Furthermore, neighbors are more likely to be able to connect the governance issues of their shared local seas with larger issues directly connected to the development of relationships and the avoidance of conflict. Without the framing of great-power rivalry, China would face greater pressure to negotiate a shared approach to regional governance of the seas connected to economic, environmental, and social development in the region.

The Philippines and The 2016 Arbitral Award

In 2013, the Philippines filed arbitration proceedings against China under UNCLOS Annex VII, initiating PCA Case No. 2013-19. The Philippines challenged China's nine-dash line claim and the occupation of several maritime features within the Philippine exclusive economic zone, arguing that China had violated Philippine sovereign rights and that the nine-dash line's assertion of historic rights over the waters of the South China Sea was incompatible with UNCLOS. The tribunal issued its award in July 2016, finding that China's claimed historic rights had no legal basis under UNCLOS and that several features China occupied were low-tide elevations incapable of generating maritime entitlements (Permanent Court of Arbitration,



2016). China had declined to participate in the proceedings from the outset and dismissed the award as null and void once issued.

The aftermath of the ruling illustrates a structural limitation in UNCLOS's enforcement architecture. Part XV of the convention provides for compulsory dispute resolution through Annex VII arbitration, which can be initiated without the consent of the opposing party. The Philippines used this mechanism to obtain a clear legal ruling—yet the ruling produced no change in China's conduct. Chinese Coast Guard vessels have repeatedly obstructed Philippine resupply missions to the BRP Sierra Madre, a deliberately grounded naval vessel at Second Thomas Shoal (Ayungin Shoal) that serves as a Philippine military outpost, using water cannons and other measures to prevent resupply (Mastro, 2021). Beijing characterizes these operations as lawful enforcement within its own waters; Manila characterizes them as violations of Philippine sovereign rights within its exclusive economic zone. Both governments invoke UNCLOS to describe the same maritime space. The case demonstrates not only that states may reject inconvenient arbitral awards, but that the convention's dispute resolution mechanism produces rulings it cannot enforce.

Japan and The Interpretation of Article 121

Japan's treatment of Okinotorishima illustrates that interpretive disputes over UNCLOS arise not only where states openly contest its rulings, but also among cooperative parties to the convention. Okinotorishima consists of two small rock outcroppings located approximately 1,740 kilometers south of Tokyo in the western Pacific Ocean. Japan classifies these features as islands under UNCLOS Article 121(1) and claims a 200-nautical-mile exclusive economic zone and an extended continental shelf on that basis (United Nations, 1982). China and South Korea contest this classification, arguing that the features satisfy the conditions of Article 121(3)—that they are rocks which cannot sustain human habitation or an economic life of their own—and should therefore generate only a 12-nautical-mile territorial sea. Japan has reinforced the outcroppings with concrete and steel structures and dispatched periodic government personnel to maintain their above-water status at high tide.

The dispute turns on the interpretive scope of Article 121(3)'s phrase "rocks which cannot sustain human habitation or an economic life of their own," which UNCLOS does not define with precision. The 2016 South China Sea Arbitration tribunal addressed similar interpretive questions in an analogous context, finding that the presence of government personnel or artificially maintained installations was insufficient to classify a feature as an island capable of sustaining an independent economic life (Permanent Court of Arbitration, 2016). Whether that reasoning applies to Okinotorishima has not been determined by any tribunal; no party has initiated formal proceedings on those specific features. The Okinotorishima case differs from the Philippine situation in one significant respect: here it is a cooperative UNCLOS party, one that has not rejected any adverse ruling, whose interpretation of Article 121 produces maritime claims that neighboring states contest as exceeding what the convention permits. This suggests that the problem of selective interpretation is at least partly a function of UNCLOS's own textual ambiguities rather than solely a matter of compliance posture.

Hybrid Governance Model

The strengths and weaknesses of global and regional agreements will determine whether the international community can effectively respond to the significant challenges that humanity currently faces. One of the most difficult is the protection of the oceans. Highly complex and dynamic factors shape the ways that governments, populations, and private interests interact with the oceans and their resources. Climate change is melting frozen regions so that previously unfeasible shipping routes and mining opportunities are becoming possible. States are pushing the limits of existing international agreements to achieve geopolitical aims such as extending territory with the construction of artificial islands. The short-term economic incentive of overfishing is causing catastrophic damage to ocean life and making previously reliable sources of food unsustainable. Pollution is damaging biodiversity and human health. Microplastic pollution has become a pervasive but often untraceable threat to all forms of life. Given rising geopolitical tensions, the unwillingness of the United States to ratify global agreements, and the use of global agreements as a tool



of advancing narrow national interest, often against the spirit of the agreement that has been made, global agreements cannot halt or reverse the various forms of damage currently being inflicted upon the oceans. Regional agreements also face challenges, as described, but the current approach is for global agreements to act as frameworks to guide and motivate further action. Based on this research, it is argued that the relationship between regional and global agreements should be flipped. States should focus on developing narrow, regional agreements that exploit local knowledge and build trust due to the shorter geographical and cultural distance between decision makers and the reality of the situation.

Global agreements attempt to impose generalized approaches on diverse regions with unique social, cultural, economic, environmental, and historical conditions. As seen from the success of the Arctic Council, however, it is more effective to develop practical solutions in specific contexts and then attempt to generalize the best practices that have been learned to more diverse contexts. As global agreements face the challenges of enforcement, States need to be incentivized to cooperate. A hybrid governance model that prioritizes regional agreements focused on narrow practical developments would create knowledge and best practices that could then be used to incentivize participation in global agreements.

One of the major weaknesses of global agreements is also what has been described as the “cloak” of “big ideological claims” that hides the “technical details” (Orford, 2021). Examples would be China defending its construction of artificial islands to exploit UNCLOS’s rules on EEZs with a “narrative of anti-imperialism and respect for sovereignty” (Orford, 2021). However, following WWII, the United States also used language of “freedom, humanitarianism, the rule of law and defence of liberty” to justify its reluctance to ratify or comply with global agreements (Orford, 2021). This framing of “great power rivalry” as a “question of values, without attending to the specific techniques, practices, actions” is mirrored in the use of global agreements to create an image of action based on values that has very little connection to what is happening in reality.

The current threats to the oceans require a focus on direct, practical action instead of spending significant amounts of time and effort on creating agreements that States can agree on but are so general that they can be interpreted in various ways and lack effective means of enforcement. However, the interconnected nature of global systems, such as the oceans, requires more than regional agreements.

A model for regional agreements that inform global agreements can be seen in the approach to air pollution. The Climate and Clean Air Coalition has praised the rapid creation of regional clean air agreements, which means that “today 95% of the Earth’s population is covered by air pollution-specific regional agreements” (CCAC Secretariat, 2023). Regional Sea Conventions are already being created with the aim of ensuring sustainable “regional development by establishing strategies and regional plans” (Marine Water Information System for Europe, 2024). However, more could be achieved by empowering regional groups to develop their own strategies based on their local knowledge and then creating systems for what has been learned to be shared in global forums.

Conclusion

The cases examined in this paper—China’s construction of artificial islands in the South China Sea and Yellow Sea, the Philippines’ arbitration proceedings against China and their aftermath, and Japan’s classification of Okinotorishima—reveal a pattern in which states across the compliance spectrum have interpreted UNCLOS selectively to support maritime claims that neighboring states dispute as exceeding what the convention permits. China rejected a binding arbitral award while exploiting the convention’s definitional ambiguities to manufacture legal and factual control over contested maritime features. The Philippines invoked UNCLOS’s own dispute resolution mechanisms, obtained a ruling in its favor, and found that the convention lacked the means to compel implementation. Japan, a cooperative UNCLOS party, has classified rock formations in ways that China and South Korea contest as inconsistent with Article 121(3), while reinforcing those formations to preserve their legal status. These cases, considered together, suggest that selective interpretation of UNCLOS is not confined to states that openly defy the convention; it also characterizes states that formally accept its authority. The pattern arises at least partly from the convention’s own textual ambiguities—on the status of artificial islands, on the threshold for island classification under Article 121, on the scope of military navigation rights in exclusive economic zones—combined with enforcement mechanisms that produce rulings without the means to ensure compliance.



These observations reflect that the international maritime law system, as currently applied, still has meaningful room for improvement at the level of implementation and enforcement.

This paper has argued that a hybrid governance model—one that prioritizes regional agreements while retaining global frameworks for broader coordination and knowledge-sharing—offers a more effective path forward than either purely global or purely regional governance. Regional agreements negotiated among neighboring states with shared interests in a specific body of water may produce more precise and enforceable rules than UNCLOS's necessarily generalized provisions. The success of the Arctic Council in generating consensus on specific regional issues offers one precedent for this approach. However, the cases reviewed here also indicate that regional dynamics are not inherently more rule-consistent than global ones. Regional negotiations face the same asymmetries of power and competing interpretations of shared rules that have complicated UNCLOS's implementation at the global level. Whether a hybrid governance model can manage these tensions more effectively than existing frameworks is a question that governance experiments in regions such as the South China Sea will need to address. What the evidence does suggest is that closing the gaps between the convention's formal provisions and their implementation in contested maritime spaces will require deliberate attention to both the precision of treaty language and the strength of enforcement mechanisms—attention that the current international maritime law system has not yet sufficiently provided.

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References

- Adewumi, I. J. (2021). Exploring the nexus and utilities between regional and global ocean governance architecture. *Frontiers in Marine Science*, 8. <https://doi.org/10.3389/fmars.2021.645557>
- Agarwal, S. K., & Agnihotri, K. K. (2022). UNCLOS and climate-induced maritime challenges: Strategic implications for the Indian Ocean Region. *Maritime Affairs: Journal of the National Maritime Foundation of India*, 18(1), 105–132.
- Bloom, E. (n.d.). *Reflections on the past and future of the Arctic Council*. Arctic Council. <https://arctic-council.org/news/reflections-on-the-past-and-future-of-the-arctic-council/>
- Capel, M. (2023, April 11). Regional environmental agreements are over twice as likely to be authorised than global agreements. *Water Magazine*. <https://www.watermagazine.co.uk/2023/04/11/regional-environmental-agreements-are-over-twice-as-likely-to-be-authorised-than-global-agreements/>
- CCAC Secretariat. (2023, September 4). *In a world full of dirty air, regional agreements on air pollution offer a glimmer of hope*. Climate & Clean Air Coalition. <https://www.ccacoalition.org/news/world-full-dirty-air-regional-agreements-air-pollution-offer-glimmer-hope>
- Center for International Law. (n.d.). The relationship between UNCLOS and IMO instruments. *National University of Singapore*. <https://cil.nus.edu.sg/publication/relationship-unclos-imo-instruments/>
- Churchill, R. (2012). The persisting problem of non-compliance with the Law of the Sea Convention: Disorder in the oceans. *The International Journal of Marine and Coastal Law*, 27(4), 813–820. <https://doi.org/10.1163/15718085-12341254>
- Churchill, R., & Hartmann, J. (2021, November 26). *Submission to the House of Lords Select Committee Inquiry: UNCLOS: Fit for purpose in the 21st century?* UK Parliament. <https://committees.parliament.uk/work/1557/unclos-fit-for-purpose-in-the-21st-century/publications/written-evidence/?page=3>
- Doherty, B. (2019, November 4). Asean summit: US condemns Chinese “intimidation” in the South China Sea. *The Guardian*. <https://www.theguardian.com/world/2019/nov/04/asean-summit-us-condemns-chinese-intimidation-in-the-south-china-sea>
- Frantzi, S. (2008). What determines the institutional performance of environmental regimes? A case study of the Mediterranean Action Plan. *Marine Policy*, 32(4), 618–629. <https://doi.org/10.1016/j.marpol.2007.11.002>



- Hughes, C. (2025, June 9). *Protecting the ocean: What is the high seas treaty?* France 24. <https://www.france24.com/en/live-news/20250609-what-is-the-high-seas-treaty>
- International Maritime Organization. (n.d.). *United Nations Convention on the Law of the Sea*. <https://www.imo.org/en/ourwork/legal/pages/unitednationsconventiononthelawofthesea.aspx>
- Kahler, M. (2017). Regional challenges to global governance. *Global Policy*, 8(1), 97–100. <https://doi.org/10.1111/1758-5899.12392>
- Kankaanpää, P., & Young, O. R. (2012). The effectiveness of the Arctic Council. *Polar Research*. <https://doi.org/10.3402/polar.v31i0.17176>
- Kohl, A. W. (2018). China's artificial island building campaign in the South China Sea: Implications for the reform of the United Nations Convention on the Law of the Sea. *Dickinson Law Review*, 122(3). <https://insight.dickinsonlaw.psu.edu/dlr/vol122/iss3/8/>
- Kraus, J. (2023, June 26). Unmoored from the UN: The struggle to ratify UNCLOS in the United States. *The SAIS Review of International Affairs*. <https://saisreview.sais.jhu.edu/unmoored-from-the-un-the-struggle-to-ratify-unclos-in-the-united-states/>
- Lee, C. (2025, January 23). *Analysts: China normalizing its claims to maritime zone shared with South Korea*. Voice of America. <https://www.voanews.com/a/analysts-china-normalizing-its-claims-to-maritime-zone-shared-with-south-korea/7947215.html>
- Maizland, L., & Fong, C. (2026, January 9). *Paris to Kyoto: The history of UN climate agreements*. Council on Foreign Relations. <https://www.cfr.org/backgrounders/paris-global-climate-change-agreements>
- Marine Water Information System for Europe. (2024, June 3). *Regional sea conventions*. Europa. <https://water.europa.eu/marine/marine/countries-and-regional-seas/regional-conventions>
- Mastro, O. S. (2021, February 17). *How China is bending the rules in the South China Sea*. The Interpreter. <https://www.lowyinstitute.org/the-interpreter/how-china-bending-rules-south-china-sea>
- Mendenhall, E. (2023). Building a regime complex for marine plastic pollution. *Cambridge Prisms: Plastics*, 1, e12. <https://doi.org/10.1017/plc.2023.12>
- Newman, J., Mukherjee, A., & Hoole, C. (2024). Constraints and enablers of regional environmental policy: Governance challenges in England and Wales. *Journal of Environmental Policy & Planning*, 26(1), 1–13. <https://doi.org/10.1080/1523908X.2023.2297793>
- Orford, A. (2021). Regional orders, geopolitics, and the future of international law. *Current Legal Problems*, 74(1), 149–194. <https://doi.org/10.1093/clp/cuab005>
- Patrick, S. (2023, March 8). *The high seas treaty is an extraordinary diplomatic achievement*. Carnegie Endowment for International Peace. <https://carnegieendowment.org/posts/2023/03/the-high-seas-treaty-is-an-extraordinary-diplomatic-achievement>
- Permanent Court of Arbitration. (2016, July 12). *South China Sea arbitration: Award (Republic of the Philippines v. People's Republic of China)*. PCA Case No. 2013-19. <https://pca-cpa.org/en/cases/7/>
- Pickerell, T., & Swift, A. (2025, June 29). *High seas treaty: Ocean protection milestone*. No Carbon Fuel. <https://www.nocarbonfuel.org/news/the-high-seas-treaty-a-20-year-journey-to-transform-ocean-governance>
- Pretlove, B., & Blasiak, R. (2018). *Mapping ocean governance and regulation*. DNV. <https://www.dnv.com/research/ocean-space/mapping-ocean-governance-and-regulation/>
- Ruta, M. (2023, June). *The rise of discriminatory regionalism*. IMF. <https://www.imf.org/en/publications/fandd/issues/2023/06/the-rise-of-discriminatory-regionalism-michele-ruta>
- Serdy, A. (2021). *A response to: UNCLOS: Fit for purpose in the 21st century? – A call for evidence from the International Relations and Defence Committee*. University of Southampton. https://www.southampton.ac.uk/~assets/doc/smmi/Serdy-a-Response-to_UNCLOS-fit-for-purpose-in-the-21st-century.pdf
- Söderbaum, F., & Hettne, B. (2006). Regional cooperation: A tool for addressing regional and global challenges. In *Meeting global challenges: International cooperation in the national interest* (pp. 179–244). International Task Force on Global Public Goods.
- Standing, G. (2022, December 12). *Here's why the UN Convention on the Law of the Sea (UNCLOS) needs an overhaul*. World Economic Forum. <https://www.weforum.org/stories/2022/12/here-s-why-un->



law-sea-overhaul/

United Nations Convention on the Law of the Sea, 450 UNTS 11 (1982).

Vanaik, A. (2020, August 12). *The UNCLOS isn't perfect and it's time we acknowledge that*. Transnational Institute. <https://www.tni.org/en/article/the-unclos-isnt-perfect-and-its-time-we-acknowledge-that>

Wam, R. (2024). Climate change loss and damage: A case for mandatory cooperation and contribution under the United Nations Convention of the Law of the Sea (UNCLOS). *UCLA Journal of Environmental Law and Policy*, 42(1). <https://doi.org/10.5070/L542163518>

Zwartz, H. (2025, July 29). China's nuclear bombers now "within range of Australia" from South China Sea. *ABC News*. <https://www.abc.net.au/news/2025-07-30/tracking-militarisation-in-the-south-china-sea/105473948>

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