Comparing COVID-19 Interventions in Democratic and Authoritarian States: A Fuzzy Logic Approach

Ethan Kurian

1. Literature Review

The relationship between political systems and public health outcomes is a widely studied topic, as researchers seek to understand how different governance structures influence health policies and their effectiveness. While several studies have indicated a connection between political regimes and health outcomes, this relationship is extremely complex and multi-dimensional. Factors such as the type of governance, policy design, and implementation must be taken into account. This literature review will delve into these themes by examining the impact of political systems on public health, the process of utilizing public policy specifically in vaccine distribution, and conclude with an exploration of fuzzy logic and its role in assessing health outcomes across various political contexts.

1.1. Computer Modeling

Computer models are a very effective and useful tool in evaluating the effectiveness of various political systems and their policies. Kraemer and King (1986) highlight this showing how computer-based models are used in U.S. federal policymaking and explore factors that influence their successful implementation. Through literature analysis and case studies, the study demonstrates that computerized models are effective in managing complex data and shaping policy decisions. This insight is the basis of the field known as ‘Computational Politics’. Winston and Finlayson explains this in a 2004 MIT Computer Science and Artificial Intelligence Laboratory, “Computational Politics is the study of political and social phenomena by computational means. Through models of human reasoning processes in conjunction with databases of historical knowledge cast in computationally-compatible representations, we hope to produce viable models of social perception, social reasoning, and social dynamics.” Though there have been numerous developments in computer modeling since 2004, its purpose and use has had little change. This development of models allows us to further examine certain situations and environments.

1.2. Political Systems

Before analyzing the connection between health outcomes (health consequences that result from actions) and political systems, one must define what a political system is. Political systems are the form of political organization declared within a state. According to Holman (1946), this includes absolute monarchies, military dictatorships, limited monarchies, constitutional monarchies, republics, and democracies.

In order to analyze the effects of political systems on health outcomes, it is crucial to first examine the relationship between political systems and health outcomes. Klomp and de Haan (2009) provides valuable insight into this relationship, investigating the basis of whether political systems and their stability are associated with health outcomes across countries. Through the use of structural equation modeling, with economic and demographic control variables, the study finds that government instability leads to generally more negative health outcomes, while more democratically functioning countries have a more positive relationship with the health of individuals. This study helps define and establish the impact that political systems have on health outcomes. Rajkumar (2008) further analyzes this link, finding that countries with better governance experience more effective public health spending, leading to reduced child mortality rates. This article helps understand how governance/political system quality can also influence health outcomes.

For example, in the case of democracies, Besley (2006) uses a panel from multiple countries in order to find whether democracies produce better health outcomes. The study found that democracies are associated with improved life expectancy and lower infant mortality. Gerring (2012) also explores the impact of democracy on human development, focusing on health indicators like infant mortality. While the immediate effects of democracy on human development are moderate, the authors find a strong relationship between historical democracy levels and improved health outcomes over time. This correlation in the political system with health outcomes serves to establish a clear link/effect.

This relationship has also been investigated in other specific political systems. For instance, Duckett and Munro (2022) investigates how healthcare programs influence the legitimacy of authoritarian regimes. From analyzing survey data from China, Duckett and Munro found that public health insurance access increases trust in the central government, while satisfaction with healthcare boosts trust in local governments. These sources explain that no matter what political systems a government has, it ultimately impacts health outcomes, and vice versa.

The book “Totalitarian and Authoritarian Regimes” by Juan José Linz, a Professor of Political Science at Yale University, explains that in our current world, democratic and authoritarian regimes serve to be the two largest/main types of political systems. Of these political systems, the United States is considered to be the most adherent example of a democracy, with China being considered the most adherent example of an authoritarian regime. Therefore, this paper will study the relationship between healthcare in the most widely used political systems of democracy and authoritarian regime as seen through the governance of the United States and China.

1.3. Public Policy

Ultimately, public policy is the actual way that these governments actually have an impact on the population. This is explained through the field of health policy (see Appendix A). Oliver (2006) examines how politics influences health policies by shaping the way health issues are recognized, defined, and addressed. Through a qualitative literature analysis, the study finds that politics plays a key role in determining public health interventions and policy implementation. This finding emphasizes the importance of understanding political backgrounds when designing effective health interventions. Tatar (2015) expands on this relationship between political systems and health outcomes, highlighting the influence of governance structures on public health policy decisions. By analyzing case studies from different countries, the study reveals that health policies are often shaped by political ideologies, budget allocations, and institutional capacity. Tatar concludes that a well-structured political system with strong healthcare institutions is critical for delivering equitable health services. The study shines a light on the importance of aligning political priorities with public health needs to achieve better health outcomes.

Public policy also has a large impact on the way countries respond to pandemics. The COVID-19 pandemic, for example. Chauhan et al. (2023) examines the impact of political and socio-economic factors on COVID-19 vaccine distribution across 217 countries. The study focuses on how citizens' trust in government and regime type influence vaccine uptake. Findings show that higher healthcare spending and stronger infrastructure led to more successful vaccine rollouts, while lower-budget nations struggled and relied on foreign donations. The research emphasizes that socio-economic factors, often related to the

government's political system, also played a role in vaccine distribution. Given the complexity and multifaceted nature of political systems' impact on public health, traditional methods may fall short in capturing this complexity, making fuzzy logic an ideal tool for modeling these systems.

1.4. Fuzzy Logic

With computer models having a large impact on political systems, one must identify the specific type used in order to create the most beneficial impact. As Moraga (2005) finds, fuzzy logic serves to be a very beneficial computer model. Fuzzy logic is a mathematical approach to handling imprecision that happens with decision making processes. Unlike traditional binary logic that uses true or false (0 or 1) values, fuzzy logic allows this to be expanded. This means that variables can have a range of values between 0 and 1, representing the extent to which a statement is true. For example, in fuzzy logic, the temperature outside wouldn't have to simply be labelled "hot" or "cold", but could be "warm" or "somewhat cold". Moraga's study differentiates fuzzy logic from classical logic systems by emphasizing its flexibility in reasoning and handling ambiguous data. Through a review of literature and mixed methods, the paper illustrates various real-world applications of fuzzy logic. This source is valuable for research on health policy modeling, as it highlights the versatility of fuzzy logic in addressing uncertainty and complexity, offering new approaches to incorporate into health outcomes evaluation.

Azar and Noruzi (2011) also further the discussion on fuzzy logic, identifying its increasing application in policymaking at both national and international levels. The study argues that traditional one-dimensional approaches to policymaking are inadequate for addressing the complex and dynamic variables of modern governance. The authors emphasize the importance of incorporating multi-faceted fuzzy thinking to enhance decision-making efficacy. The study concludes that fuzzy thinking enables organizations to make better decisions and adapt policies to real-world complexities, making it a valuable framework for improving policy outcomes.

An actual example of this is seen from Cisneros-Montemayor et. al (2018). Similar to the method of this paper, which is expanded upon later, the study uses criteria to create an evaluation/conceptual framework which forms the basis for the subsequent model. Then, Cisneros-Montemayor uses the fuzzy logic model in order to evaluate the effectiveness of public policy contributing to environmental sustainability.

1.5. Research Question

With the connection between the effects of political systems on health outcomes established, and a spotlight on how computer models, specifically fuzzy logic, can be used to decipher the effectiveness of said political systems, this leads to the question being asked: How do democracy and authoritarian governance impact the effectiveness of federal COVID-19 interventions seen through the United States and China?

1.6. Foundational Sources

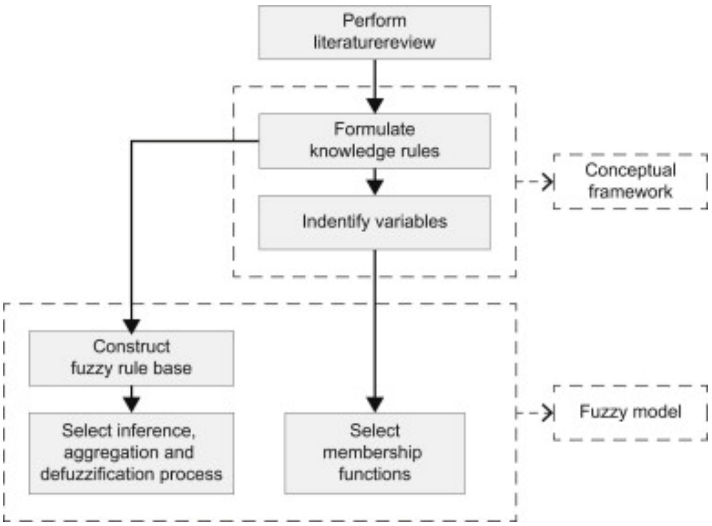
de Vos et al. (2013), a study that evaluates the effectiveness of international environmental regimes through a combination of literature review and fuzzy logic computer models to demonstrate the success of specific policies in reducing harmful substances, served as a foundational source throughout this paper's method. This source is particularly valuable as it provides a methodological framework that can be adapted to health policy research. By integrating fuzzy logic, this approach offers insights into assessing the influence of political

systems on health policy effectiveness, identifying key factors and addressing potential gaps in policy evaluation.

2. Method

Following a similar method to de Vos, this section aims to outline the method for assessing the effectiveness of COVID-19 interventions based on political systems, represented by separate countries. This was done by adopting a definition of intervention effectiveness, conducting a literature analysis to gather relevant knowledge on COVID-19 intervention strategies, and formalizing this knowledge into a set of rules and a conceptual framework. After reviewing various modeling approaches, fuzzy logic was identified as the most suitable technique. The final part of this section details the process of translating the conceptual framework into a fuzzy model. Figure 1 below serves as a visual construction of this process.

Figure 1: Visual of Conceptual Framework



de Vos, M. (2013). Description of the various steps in the process of developing a conceptual framework and a fuzzy model to analyse regime effectiveness. [Diagram]. ScienceDirect. https://www.sciencedirect.com/science/article/pii/S1364815212002241?via%3Dihub

2.1. Constructing a conceptual framework

Due to the constraints of the AP research course, it wasn't practical to develop an entire conceptual framework on one's own. That is why the decision to look at separate reputable sources to identify and establish a credible conceptual framework was made. Moy (2023) served as a great source for this using what is known as the "Constructing Policy Interventions" (CPI) framework to compare and evaluate the impacts of governance systems on pandemic response outcomes. The CPI framework provided a structured lens for assessing governance-driven policy responses to public health crises. It organized interventions into four core domains as identified by Table 1.

Table 1: Domains of Public Health Crisis Intervention

Containment:	Policies aimed at limiting the spread of the virus (Travel Restriction and Quarantine, Testing and Contact Tracing, Public Communication)
Prevention and Care:	Measures to improve healthcare delivery and reduce disease severity (Vaccine Campaigns, Infection Control measures, Public Health Guidance)
Economic Interventions:	Policies to mitigate economic fallout (Fiscal Stimulus Packages, Monetary Policy Adjustments, Support for Businesses and Individuals)
Health technology interventions:	Innovative technological response of industry (Health Research systems to assist in Testing, Tracing, and Treating Individuals)

As the “Health technology interventions” domain doesn’t come directly as a result of policy implementation, it was disregarded in this paper. Each domain is evaluated on a 0-4 scale based on its level of implementation and measurable outcomes. A higher score indicated greater policy success and effectiveness. By employing the CPI framework, this study provided a comprehensive and systematic approach to evaluate how democracy and authoritarian governance impact the effectiveness of COVID-19 interventions.

2.2. Selecting Literature

To ensure a fair and accurate comparison between different political systems, a consistent methodology was implemented throughout the literature analysis. Research was conducted using peer-reviewed academic databases such as JSTOR and ScienceDirect, focusing on keywords including “COVID-19 interventions”, “health policy effectiveness”, and “governance models”. When selecting sources for each country, consistency was prioritized by using similar types of sources across systems. For instance, if a government report was used for one country, the aim was to use a comparable report or methodology for the other to maintain data comparability. Additionally, data was incorporated from international organizations, such as the International Monetary Fund (IMF), particularly when evaluating economic interventions. This ensured that stimulus efforts and financial relief responses were assessed using neutral and standardized metrics across nations.

2.3. Why Fuzzy Logic

As previously mentioned in this paper, fuzzy logic has many advantages. In this case, the one main advantage was identified by Moraga (2005). The paper differentiated fuzzy logic from classic logic systems and emphasized its flexibility in reasoning and handling ambiguous data. This was especially necessary in this study as not all included data was crisp and the framework that was used simplifies this down to a gradient rather than clear answers.

2.4. Constructing a fuzzy model

2.4.1. Quantification and fuzzification of variables

As the CPI from Moy (2023) already provided a gradient from 0-4 that each domain was able to be weighted on, the fuzzy model became simpler to create. These levels were classified as none (0); minimum (1); medium (2); significant (3), very significant (4). However, the classification of these levels involves some subjectivity, as the interpretation of what constitutes 'significant' or 'very significant' intervention may vary across contexts. Despite this, the framework was useful for capturing relative differences in pandemic responses while acknowledging the complexities of governance in crisis situations.

2.4.2. Fuzzy rule base construction

As de Vos (2023) explains, “The heart of the fuzzy logic method is the fuzzy rule base… a set of reasoning rules that reflects the knowledge on the system of interest, which in our case is based on the robust findings from international environmental regime literature as represented by the conceptual framework and its associated knowledge rules.” Below, the CPI framework was processed into a fuzzy rule base, presented through examples that illustrate the creation of the rules through IF–THEN statements. For example, “**IF** Containment is significant **THEN** COVID-19 management is **high**.” This rule was then translated into python code as part of the fuzzy logic model (See Appendix B for further explanation). Using this, a full list of rules was created (Appendix C).

2.4.4. Defuzzification: calculation of regime effectiveness

The results from the fuzzy base rules leave a fuzzy conclusion on the effectiveness of various political systems. The final step in the framework involved translating this fuzzy information back into a numerical value. This process, as de Vos (2023) explains, is called “defuzzification” that “use[s] the ‘centre of gravity’ method, which determines the specific output value (centroid) which divides the area under the membership function into two equally sized subareas.” But ultimately, as Jang (1993) explains, it results in a “final output value… [giving a] numerical indication… in a given situation.” In this situation, the final numerical value gave the effectiveness of the various political systems in COVID-19 interventions.

3. Results

3.1. Containment

3.1.1. United States

Travel Restrictions and Quarantine/Isolation

The United States implemented travel restrictions, including bans on travelers from specific countries and public advisories against non-essential travel. However, these measures were often introduced after community transmission had already begun, limiting their

effectiveness. A study published by Karen Ann Grepin in BMJ Global Health indicates that delays in implementing travel restrictions may have contributed to the virus's spread.

In addition to travel restrictions, the U.S. recommended self-quarantine and isolation for individuals exposed to or infected with COVID-19. However, enforcement varied across states, and compliance was inconsistent. Lauren Breeher, an MD in the Division of Preventive Medicine at the Mayo Clinic Proceedings, highlights that the lack of a unified national strategy led to disparities in implementation. Given the delayed travel bans and inconsistent enforcement of quarantine policies, the combined effectiveness of these measures is rated as medium (2) in containment effectiveness.

Testing and Contact Tracing

Initially, the U.S. faced significant challenges with testing availability and capacity, hindering early detection and isolation of cases. Contact tracing efforts were similarly fragmented and under-resourced. McClain (2020) at the Pew Research Center emphasizes that delays in testing and insufficient contact tracing infrastructure impeded effective containment. Therefore, testing and contact tracing policies are rated as minimum (1) in containment effectiveness.

Public Communication and Health Campaigns

Public communication in the U.S. during the pandemic was marked by mixed messages from various levels of government and health agencies. This inconsistency led to public confusion and varied adherence to recommended health measures. McClain (2020) continues this in another Pew Research Center article where inconsistent messaging may have undermined public trust and compliance. As a result, public communication and health campaigns are rated as minimum (1) in effectiveness.

Overall Containment in the U.S.

In summary, the U.S. response to COVID-19 containment exhibited variability in policy implementation and effectiveness, with particular challenges in testing, contact tracing, and public communication. By averaging the overall effectiveness of task specific policies, containment policies in the U.S. receive a score on the CPI of 1.33.

3.1.2. China

Travel Restrictions and Quarantine/Isolation

China implemented extensive travel bans, including international flight suspensions and domestic movement limitations especially in and out of Wuhan during the early stages of the outbreak. In addition to this, Jiao et al. (2022) explains the extent of these policies where China, “Temporarily closed seven border stations”, “Implemented a movement against illegally crossing the nation's borders”, “Strengthened health quarantine at ports and epidemiological history checks”, and “Implemented the health declaration system for entry and exit personnel.” This combination of policies were vital to the COVID-19 response in order to contain the disease and thus received a very significant (4) on travel restriction containment policies.

Testing and Contact Tracing

China implemented widespread testing and rigorous contact tracing, enabling the early detection and isolation of cases. According to the CDC, nucleic acid amplification tests (NAATs)

are “highly sensitive and highly specific tests that detect one or more viral ribonucleic acid (RNA) genes… used for COVID-19 testing.” As Jiao et al. (2022) continues, China also “organized the first full nucleic acid testing, and later organized several rounds of district-wide and city-wide nucleic acid testing” and ultimately screened the large population using multiple rounds of testing. In addition to this, the adoption of active close contact tracing using technology such as drones was found to be very effective in identifying and preventing transmission. As a result, China received a very significant (4) on its testing and contact tracing containment policies.

Public Communication and Health Campaigns

China launched extensive public health campaigns to educate citizens on COVID-19 prevention, including mask-wearing, social distancing, and hygiene measures. The government utilized mass media, social media platforms, and text messaging to share information rapidly. Community-level engagement was also prioritized, with local authorities enforcing guidelines and distributing supplies. Yang and Han (2023) describe the COVID-19 Vaccine Communication Campaign (CVCC) as being sustained by top-down political pressure, involving components such as ideological education among health workers, media promotion, and persuasive communication with residents. While these efforts significantly enhanced vaccine acceptance, challenges like stigmatizing vaccine refusers and insufficient stakeholder collaboration were noted. Overall, these public communication and health campaigns receive a significant (3) rating on the containment effectiveness scale.

Overall Containment in China

By considering and averaging the implementation of travel restrictions, testing and contract tracing, and public communication and health campaigns, we find China to have an overall containment rating of 3.67.

3.2. Prevention and Care

3.2.1 United States

Vaccination Campaigns

The U.S. launched an extensive COVID-19 vaccination campaign, prioritizing rapid vaccine development and distribution. The CDC recommended vaccinations for all eligible individuals, with booster doses for high-risk populations. Despite initial supply challenges, mass vaccination sites, mobile units, and pharmacy partnerships expanded accessibility. However, vaccine hesitancy and misinformation limited full coverage, as demonstrated by Yasmin et al. (2021), preventing a higher CPI score. Given its effectiveness in reducing hospitalizations and deaths but the uneven uptake, the vaccination campaign receives a significant (3) on the CPI scale.

Infection Control Measures

The CDC issued infection prevention and control (IPC) guidance, emphasizing the use of personal protective equipment (PPE), sanitation practices, and screening protocols in healthcare settings. However, adherence to these guidelines varied significantly by state and facility, and shortages of PPE in early 2020 weakened the response. While infection control policies were beneficial, De Francia (2023) highlights the inconsistent implementation and

supply chain issues that limited their overall impact, earning them a medium (2) rating on the CPI scale.

Public Health Guidance

The CDC and other federal agencies provided evolving public health recommendations, including mask mandates, social distancing, and hygiene practices. However, frequent policy shifts and political divisions led to public confusion and reduced compliance. Masking policies varied widely across states, and enforcement was inconsistent. As a result, while guidance was present, its effectiveness was limited, leading to a minimum (1) rating on the CPI scale.

Overall Prevention/Care in the U.S.

The United States' prevention and care policies combined vaccination efforts, infection control measures, and public health recommendations. However, varying levels of adherence, supply chain issues, and political challenges influenced their overall effectiveness. By averaging on the CPI scale we get an overall score of 2 for prevention/care policies in the U.S.

3.2.2 China

Vaccination Campaigns

China launched an extensive COVID-19 vaccination campaign to curb the virus, administering millions of doses across the country. Initially, Yang (2023) explains how China prioritized healthcare workers, the elderly, and high-risk populations, later expanding vaccination to the general population. However, as Xu (2021) identifies, limited vaccine acceptance in certain regions and challenges of reaching rural areas, impacted overall coverage. Despite these hurdles, the vaccine campaign was instrumental in reducing severe cases and deaths, earning it a significant (3) on the CPI scale.

Infection Control Measures

China's infection control measures were stringent, as Huang (2023) highlights, including mass quarantines, strict lockdowns, extensive contact tracing, and mandatory quarantine for travelers. Local authorities imposed lockdowns in areas with outbreaks, restricting movement and mandating testing. These measures were critical in the early stages of the pandemic and are widely credited with keeping case numbers low in comparison to other countries. The enforcement of quarantine, particularly in high-risk areas, ensured that outbreaks were contained quickly, earning a very significant (4) rating on the CPI scale for their effectiveness.

Public Health Guidance

China's public health guidance involved a combination of prevention measures, such as mask-wearing, social distancing, and hand hygiene. Gao (2021) explores how the government widely promoted these measures through public campaigns, emphasizing the importance of wearing masks and social distancing, especially in crowded areas. While these policies were broadly effective, the success of the guidance was impacted by the frequent changes in public health recommendations, particularly as the virus evolved. Overall, the public health guidance was impactful but less consistently applied in later stages, earning it a significant (3) rating on the CPI scale.

Overall Prevention/Care in China

China's prevention and care policies, which included vaccination efforts, infection control measures, and public health guidance, were essential to managing the COVID-19 pandemic. The high level of enforcement and the early response were critical to China's success, but challenges in public compliance and adaptation in the later phases lowered the overall impact. Using the CPI scale, we determined an average score of 3.33 for the effectiveness of China's prevention/care policies.

3.3. Economic

3.3.1 United States

Fiscal Stimulus Packages

The U.S. government enacted several substantial fiscal stimulus packages to provide immediate relief to individuals, businesses, and healthcare providers. Notably, the American Rescue Plan Act of 2021, explained by the U.S. Department of the Treasury, allocated approximately $1.9 trillion, offering direct payments to individuals, extended unemployment benefits, and support for small businesses. These measures were instrumental in sustaining household incomes and consumer spending during periods of economic uncertainty. According to Laura Wheaton, a senior fellow at the Urban Institute, the packages even drove a dramatic decline in poverty. The significant scale and direct impact of these interventions warrant a very significant (4) rating on the CPI scale.

Monetary Policy Adjustments

In response to the economic downturn, the Federal Reserve implemented aggressive monetary policies (actions to maximize employment, stabilize prices, and moderate long-term interest rates), such as reducing the federal funds rate to near zero. Additionally, the Federal Reserve engaged in large-scale asset purchases, significantly increasing its holdings of Treasury securities and agency mortgage-backed securities (MBS). From February 2020 to February 2022, Ihrig (2024) explains that the Federal Reserve's balance sheet expanded by approximately $4.5 trillion, with cumulative net purchases of Treasury securities and agency MBS reaching around $3.8 trillion and $700 billion, respectively. These actions aimed to lower borrowing costs and support economic activity. While effective in stabilizing financial markets and encouraging investment, the long-term implications of these policies, such as inflationary pressures, have been impactful in the status quo. Given their hefty influence on the economy, these monetary policy adjustments receive a significant (3) rating on the CPI scale.

Support for Businesses and Individuals

The U.S. implemented various programs to support businesses and individuals, including the Paycheck Protection Program (PPP), which provided forgivable loans to small businesses to retain employees, and expanded unemployment insurance benefits. The Peter G. Peterson Foundation explains how these initiatives were crucial in preventing widespread layoffs and supporting consumer spending. However, challenges such as delays in fund distribution and disparities in access to resources limited the overall effectiveness of these programs. Considering their positive impact on economic stability, these support measures are rated as significant (3) on the CPI scale.

Overall Economic Policy in the United States

The United States' economic response to the COVID-19 pandemic involved comprehensive fiscal and monetary policies aimed at stabilizing the economy and supporting recovery. While these measures were largely effective in mitigating immediate economic impacts, challenges such as inflation and disparities in program access have influenced their overall effectiveness. Using the CPI scale, we get an average of 3.33 for United States economic intervention effectiveness.

3.3.2 China

Fiscal Stimulus Packages

China introduced several fiscal stimulus measures to mitigate the economic slowdown, including tax cuts, financial support for small businesses, and direct government spending on infrastructure projects. Notably, Arendse Huld, a policy researcher at China Briefing, highlights that China allocated 12.8 trillion Yuan (US$1.9 trillion) in 2020 as a stimulus package. Huld explains how these measures were designed to stabilize employment and support businesses hit by the pandemic. These actions provided vital economic support and were effective in stimulating growth during the recovery phase, particularly in infrastructure and manufacturing sectors. As a result, China's fiscal response to the pandemic receives a very significant (4) rating on the CPI scale due to the immediate and impactful nature of these measures.

Monetary Policy Adjustments

To stimulate economic activity, the People's Bank of China (PBC) made several monetary policy adjustments, including reducing interest rates and lowering the reserve requirement ratio (RRR) for banks. These measures aimed to increase the flow of money in the economy, reduce borrowing costs, and encourage lending. The PBoC also used targeted lending programs to support small and medium-sized enterprises (SMEs). Another primary strategy involved liquidity injection, as identified by the International Monetary Fund, by introducing money to the economy through loan. While these monetary measures provided liquidity and helped stabilize the financial system, their effectiveness was somewhat limited by the global economic environment and domestic demand issues. The monetary policy adjustments played a significant role in supporting China's recovery, earning them a **significant (3)** rating on the CPI scale.

Support for Businesses and Workers

China implemented multiple initiatives aimed at supporting businesses and workers, including tax deferrals, direct financial support for SMEs, and subsidies for industries heavily affected by the pandemic such as the tourism, retail, and transportation sectors. According to the International Monetary Fund, the government also introduced a "temporary employment protection" program to support workers' wages and employment. These initiatives were instrumental in preventing mass layoffs and keeping businesses afloat, especially SMEs, which form a key part of China's economy. However, challenges such as uneven distribution of funds and the temporary nature of some programs limited the overall reach of these measures. These support initiatives are thus rated as **significant (3)** on the CPI scale.

Overall Economic Policy in China

China's economic response to the COVID-19 pandemic involved comprehensive fiscal and monetary policies aimed at stabilizing the economy and promoting recovery. These policies were largely effective in stimulating growth, stabilizing financial markets, and providing critical support to businesses and workers. However, certain limitations in program accessibility and global economic challenges affected the full impact of these measures. As a result, China's economic intervention effectiveness receives an average CPI score of 3.33.

3.4. Fuzzy Model

The table on the next page produces the final CPI scores for each domain of each country.

Table 2: Final CPI Averages for Each Domain

Domain	United States	China
Containment	1.33 (Minimum to Medium)	3.67 (Significant to Very Significant)
Prevention and Care	2 (Medium)	3.33 (Significant to Very Significant)
Economic	3.33 (Significant to Very Significant)	3.33 (Significant to Very Significant)

These values are then inputted into the fuzzy logic model (See Appendix D). This results in an overall rating of 2.08 for the United States and 3.16 for China.

4. Analysis

The findings of this study highlight the significant role that political systems play in shaping the effectiveness of COVID-19 interventions. The contrasting outcomes reveal that policy success doesn't just stem from intent, but rather from execution, trust, and political dynamics. The U.S. experience highlights how democratic values like individual freedom and decentralized governance can sometimes undermine collective action during emergencies. In contrast, China's centralized model enables rapid and cohesive action, but raises concerns about human rights and transparency. This matters because it challenges the assumption that more freedom always leads to better outcomes, especially during global health emergencies.

This serves as precedent for policymakers, global health leaders, and the public to show that both models have trade-offs. Democracies need ways to maintain public trust and cohesion without sacrificing core freedoms, while authoritarian regimes must grapple with ethical implications of control while maintaining effectiveness.

Ultimately, this analysis reveals that evaluating the effectiveness of health interventions requires more than just outcome metrics—it demands a deeper understanding of how governance shapes human behavior, trust, and accountability during crises.

5. Conclusion

Understanding how political systems affect health interventions is crucial for policymakers, public health officials, and researchers. This research bridges a critical gap by applying fuzzy logic modeling to compare the effectiveness of federal interventions in democratic and authoritarian systems, specifically the U.S. and China. By quantifying the influence of governance structures on health outcomes, this study not only reveals the strengths and weaknesses of different political regimes but also provides a scalable framework for evaluating policy performance across diverse political contexts.

5.1. Limitations

Despite its insights, this study has limitations. Data reliability is a concern, as COVID-19 reporting varied across countries, leading to inconsistencies. Underreporting, differences in testing, and record-keeping disparities may have influenced results. The CPI fuzzy logic framework, while structured, remains somewhat subjective, as the assignment of fuzzy sets and weightings can impact conclusions. Additionally, pandemics are highly complex, with factors like economic capacity, healthcare infrastructure, and cultural attitudes playing significant roles. While multiple variables are considered, no single model can fully capture the intricacies of pandemic response.

5.2. Future Directions

Future research should explore the role of cultural and societal factors in shaping health policy effectiveness, particularly in democratic versus authoritarian contexts. Expanding the application of fuzzy logic to evaluate other global health crises, such as influenza outbreaks or future pandemics, would further validate the methodology used in this study. Additionally, comparative analyses involving hybrid political systems could provide deeper insights into how mixed governance models navigate health emergencies. Finally, integrating qualitative data, such as interviews with policymakers and public health experts, could offer a richer understanding of the decision-making processes behind health interventions.

Ultimately, this study contributes to the growing discourse on political structures and health outcomes, emphasizing the need for adaptable, data-driven approaches in crisis response. By leveraging computational models like fuzzy logic, policymakers can refine health strategies to achieve more effective and equitable health interventions globally.

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Appendix A
Definitions

Health Policy: Actions and decisions taken by governments and other actors to achieve specific health care goals within a society (Oliver, 2006).
Political Systems: The system of government in a nation, including the structure, functions, and processes of its political institutions (Holman, 1946).
Public Policy: A system of laws, regulatory measures, courses of action, and funding priorities concerning a given topic promulgated by a governmental entity or its representatives (Tatar, 2015).
Governance: The processes of interaction and decision-making among the actors involved in a collective problem that lead to the creation, reinforcement, or reproduction of social norms and institutions (Rajkumar, 2008).
Computer Modeling: The process of creating a mathematical representation of a real-world system to study its behavior and predict its outcomes (Kraemer, 1986).
Fuzzy Logic: A form of many-valued logic in which the truth values of variables may be any real number between 0 and 1 inclusive, used to handle the concept of partial truth (Moraga, 2005).
Socio-Economic Factors: The social and economic factors that influence an individual's or a group's quality of life, including income, education, and social status (Chauhan, 2023).
Conceptual Framework: An analytical tool with several variations and contexts. It is used to make conceptual distinctions and organize ideas (de Vos, 2013).
Constructing Policy Interventions (CPI) Framework: A structured approach to comparing and evaluating the impacts of governance systems on pandemic response outcomes, organizing interventions into containment, prevention and care, economic, and health technology domains (Moy, 2023).
Containment Policies: Policies aimed at limiting the spread of a disease, such as travel restrictions, quarantine, and contact tracing (Moy, 2023).
Prevention and Care Measures: Actions taken to prevent disease and provide healthcare, including vaccination campaigns and public health guidance (Moy, 2023).
Economic Interventions: Government policies designed to mitigate economic impacts, such as fiscal stimulus and monetary policy adjustments (Moy, 2023).
Quantification and Fuzzification of Variables: The process of assigning numerical values to variables and converting them into fuzzy sets with degrees of membership (Divya, 2022).
Fuzzy Rule Base: A set of IF-THEN rules that define the relationships between fuzzy variables in a fuzzy logic system (de Vos, 2013).
Defuzzification: The process of converting a fuzzy output back into a crisp numerical value (Jang, 1993).

Appendix B
Types of Fuzzy Logic Rules

1. Single Variable Rules

Certain knowledge rules from the CPI framework describe the effect of a single input to a single output. For example, containment measures are measured on a 0-4 scale, where a higher implementation level correlates with improved effectiveness. Thus, the fuzzy rule can be expressed as:

a) **IF** Containment is significant **THEN** COVID-19 management is **high**.
b) **IF** Containment is minimum **THEN** COVID-19 management is **low**.

Here, the rule assumes that containment policies play an important role in limiting viral spread and affect the success of pandemic management.

2. Combined Variable Rules

Some rules reflect the combination of two domains on the output variable, such as the relationship between economic interventions and prevention measures. While containment may allow for the control of virus transmission, economic intervention can also factor in to support this through social stability. An example of these combined rules can be seen as:

a) **IF** Containment is significant **AND** Economic Interventions are significant **THEN** COVID-19 management is very **high**.
b) **IF** Containment is significant **AND** Economic Interventions are minimum **THEN** COVID-19 management is **medium**.

3. Knowledge Gaps

While the CPI framework is very useful, it doesn't provide all the answers for all possible combinations. For example, while containment is well documented, there may be some cases in which data about economic interventions is scarce or absent. This leads to the need of neutral assumptions where there is a lack of knowledge. Such a scenario would be defined as:

a) **IF** Containment is medium **THEN** COVID-19 management is **medium**.
b) **IF** Economic Interventions are low **THEN** COVID-19 management is **medium**.

These rules ensure that no scenario within the fuzzy input space is left unaddressed, thereby allowing the fuzzy model to operate under conditions of incomplete knowledge.

Appendix C
Fuzzy Logic Rules

Single Variable Rules

Containment:

- IF Containment is none THEN COVID-19 management is very low.
- IF Containment is minimum THEN COVID-19 management is low.
- IF Containment is medium THEN COVID-19 management is medium.
- IF Containment is significant THEN COVID-19 management is high.
- IF Containment is very significant THEN COVID-19 management is very high.

Prevention and Care:

- IF Prevention and Care is none THEN COVID-19 management is very low.
- IF Prevention and Care is minimum THEN COVID-19 management is low.
- IF Prevention and Care is medium THEN COVID-19 management is medium.
- IF Prevention and Care is significant THEN COVID-19 management is high.
- IF Prevention and Care is very significant THEN COVID-19 management is very high.

Economic Interventions:

- IF Economic Interventions are none THEN COVID-19 management is very low.
- IF Economic Interventions are minimum THEN COVID-19 management is low.
- IF Economic Interventions are medium THEN COVID-19 management is medium.
- IF Economic Interventions are significant THEN COVID-19 management is high.
- IF Economic Interventions are very significant THEN COVID-19 management is very high.

Combined Variable Rules

Containment and Economic Interventions:

- IF Containment is significant AND Economic Interventions are significant THEN COVID-19 management is very high.
- IF Containment is significant AND Economic Interventions are minimum THEN COVID-19 management is medium.
- IF Containment is minimum AND Economic Interventions are significant THEN COVID-19 management is medium.
- IF Containment is minimum AND Economic Interventions are minimum THEN COVID-19 management is low.

Prevention and Care and Economic Interventions:

- IF Prevention and Care is significant AND Economic Interventions are significant THEN COVID-19 management is very high.

- IF Prevention and Care is significant AND Economic Interventions are minimum THEN COVID-19 management is medium.
- IF Prevention and Care is minimum AND Economic Interventions are significant THEN COVID-19 management is medium.
- IF Prevention and Care is minimum AND Economic Interventions are minimum THEN COVID-19 management is low.

Handling Knowledge Gaps

Neutral Assumptions:

- IF Containment is medium THEN COVID-19 management is medium.
- IF Prevention and Care is medium THEN COVID-19 management is medium.
- IF Economic Interventions are low THEN COVID-19 management is medium.

Appendix D
Python Fuzzy Model Code

```python
import numpy as np
import skfuzzy as fuzz
from skfuzzy import control as ctrl
import matplotlib.pyplot as plt

containment = ctrl.Antecedent(np.arange(0, 5, 1), 'containment')
prevention_care = ctrl.Antecedent(np.arange(0, 5, 1), 'prevention_care')
economic_interventions = ctrl.Antecedent(np.arange(0, 5, 1), 'economic_interventions')
covid_management = ctrl.Consequent(np.arange(0, 5, 1), 'covid_management')

membership_labels = ['none', 'minimum', 'medium', 'significant', 'very_significant']
membership_functions = [
    [0, 0, 0], [0, 1, 2], [1, 2, 3], [2, 3, 4], [3, 4, 4]
]

for var in [containment, prevention_care, economic_interventions]:
    for label, shape in zip(membership_labels, membership_functions):
        var[label] = fuzz.trimf(var.universe, shape)

covid_management['very_low'] = fuzz.trimf(covid_management.universe, [0, 0, 1])
covid_management['low'] = fuzz.trimf(covid_management.universe, [0, 1, 2])
covid_management['medium'] = fuzz.trimf(covid_management.universe, [1, 2, 3])
covid_management['high'] = fuzz.trimf(covid_management.universe, [2, 3, 4])
covid_management['very_high'] = fuzz.trimf(covid_management.universe, [3, 4, 4])

rules = [
    ctrl.Rule(containment['none'], covid_management['very_low']),
    ctrl.Rule(containment['minimum'], covid_management['low']),
    ctrl.Rule(containment['medium'], covid_management['medium']),
    ctrl.Rule(containment['significant'], covid_management['high']),
    ctrl.Rule(containment['very_significant'], covid_management['very_high']),
    ctrl.Rule(prevention_care['none'], covid_management['very_low']),
    ctrl.Rule(prevention_care['minimum'], covid_management['low']),
    ctrl.Rule(prevention_care['medium'], covid_management['medium']),
    ctrl.Rule(prevention_care['significant'], covid_management['high']),
    ctrl.Rule(prevention_care['very_significant'], covid_management['very_high']),
    ctrl.Rule(economic_interventions['none'], covid_management['very_low']),
    ctrl.Rule(economic_interventions['minimum'], covid_management['low']),
    ctrl.Rule(economic_interventions['medium'], covid_management['medium']),
    ctrl.Rule(economic_interventions['significant'], covid_management['high']),
```

```
    ctrl.Rule(economic_interventions['very_significant'], covid_management['very_high']),
    ctrl.Rule(containment['significant'] & economic_interventions['significant'],
covid_management['very_high']),
    ctrl.Rule(containment['significant'] & economic_interventions['minimum'],
covid_management['medium']),
    ctrl.Rule(containment['minimum'] & economic_interventions['significant'],
covid_management['medium']),
    ctrl.Rule(containment['minimum'] & economic_interventions['minimum'],
covid_management['low']),
    ctrl.Rule(prevention_care['significant'] & economic_interventions['significant'],
covid_management['very_high']),
    ctrl.Rule(prevention_care['significant'] & economic_interventions['minimum'],
covid_management['medium']),
    ctrl.Rule(prevention_care['minimum'] & economic_interventions['significant'],
covid_management['medium']),
    ctrl.Rule(prevention_care['minimum'] & economic_interventions['minimum'],
covid_management['low']),
    ctrl.Rule(containment['medium'], covid_management['medium']),
    ctrl.Rule(prevention_care['medium'], covid_management['medium']),
    ctrl.Rule(economic_interventions['medium'], covid_management['medium']),
]

covid_ctrl = ctrl.ControlSystem(rules)
covid_sim = ctrl.ControlSystemSimulation(covid_ctrl)

containmentVal = 3.67
prevention_careVal = 3.33
economic_interventionsVal = 3.33

covid_sim.input['containment'] = containmentVal
covid_sim.input['prevention_care'] = prevention_careVal
covid_sim.input['economic_interventions'] = economic_interventionsVal
covid_sim.compute()

covid_management_effectiveness = covid_sim.output['covid_management']
print("COVID-19 Management Effectiveness:", covid_management_effectiveness)
```