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Tariff Policies, Animal Disease Risks, and Food Security: A Comparative Simulation of West African and U.S. Agricultural Systems

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Abstract

Agricultural systems are increasingly shaped by the intersection of trade policies, biosecurity risks, and the overarching imperative of food security. Tariff regimes influence the cost, accessibility, and competitiveness of livestock and poultry products, while outbreaks of transboundary animal diseases such as avian influenza or foot-and-mouth disease disrupt supply chains and strain public health systems. From a global perspective, the balance between liberalized trade and protective tariffs remains delicate, particularly when weighed against the need to maintain resilient and safe food systems. This study employs a comparative simulation model to examine the interactions between tariff policies, animal disease risks, and food security outcomes in West African and U.S. agricultural systems. The U.S. model emphasizes advanced biosecurity infrastructure, heavily mechanized production, and tariff policies shaped by global competitiveness. By contrast, West African systems are characterized by fragmented supply chains, reliance on smallholder farmers, and heightened vulnerability to disease shocks due to weaker veterinary and monitoring frameworks. Simulation results reveal that while tariffs can protect domestic producers in West Africa, they may simultaneously elevate consumer food prices, exacerbating food insecurity in vulnerable populations. Conversely, in the U.S., reduced tariffs paired with strong biosecurity capacity enhance system resilience but may expose domestic markets to external price volatility. The comparative analysis highlights the importance of harmonizing tariff policies with robust animal health measures and adaptive safety nets. Ultimately, the findings underscore that food security is best safeguarded when trade policies are aligned with risk management strategies, ensuring both affordability and stability across diverse agricultural contexts.

Keywords: Tariff policies; Animal disease risks; Food security; Simulation modelling; West African agriculture; U.S. Agricultural systems

1. Introduction

Food security remains one of the most pressing global challenges, shaped by demographic growth, climate change, and shifting trade dynamics [1]. Despite significant progress in agricultural productivity, regions such as Sub-Saharan Africa continue to face high levels of food insecurity, exacerbated by climate-induced yield fluctuations and market instability [2]. In contrast, developed economies like the United States rely on highly mechanized and trade-integrated systems, which create both opportunities and vulnerabilities [3].

Agricultural trade serves as a critical buffer, enabling countries with production shortfalls to access external supplies while creating income streams for exporters [4]. However, reliance on trade also exposes economies to price shocks, protectionist policies, and tariff disputes, all of which may undermine food availability and affordability [5]. Tariff regimes influence not only the flow of commodities but also shape incentives for investment in disease control and agricultural innovation [6].

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Another important dimension is disease resilience. Outbreaks of animal diseases such as avian influenza or African swine fever can devastate livestock sectors, leading to trade bans, culling, and income losses. Such shocks propagate through supply chains, amplifying price volatility and threatening household food access [1]. For instance, border closures during animal health crises in West Africa restricted protein supplies and destabilized informal markets, which provide livelihoods for millions [7].

Thus, the intersection of tariffs, disease resilience, and trade policy directly links to food security outcomes at both regional and global levels. Understanding these linkages is essential for designing strategies that balance national protection with international cooperation.

1.1. Research Problem and Rationale

The key research problem addressed here lies in analyzing how tariff regimes interact with animal disease shocks to affect food security outcomes. While tariffs are often employed to protect domestic agriculture, they may also restrict imports during crises, thereby compounding shortages and escalating prices [2]. Conversely, in settings where tariffs are low and markets are open, disease outbreaks abroad can rapidly spill into domestic supply chains through global trade networks [8].

This tension raises the central question: how can policymakers reconcile the protective intent of tariffs with the need for resilience in the face of unpredictable disease events? A comparative focus on West Africa and the United States is particularly relevant. West Africa's food systems are marked by heavy reliance on informal cross-border trade, weak veterinary infrastructure, and tariff variability across regional blocs [4]. By contrast, the United States operates within a highly regulated and globally integrated market, where tariff disputes often emerge within broader trade negotiations.

By examining both contexts, the study provides insights into the differential vulnerabilities and adaptive capacities of distinct agricultural systems. Such comparative analysis offers lessons for designing more resilient trade frameworks that balance sovereignty, disease preparedness, and food security.

1.2. Structure of the Article

The article is organized into several sections that collectively build a simulation-driven comparative analysis. Following this introduction, Section 2 reviews relevant literature on food security, tariffs, and disease resilience, highlighting conceptual and empirical gaps. Section 3 outlines the methodological approach, including the simulation framework designed to model interactions between tariff regimes and animal disease shocks. This framework incorporates both deterministic and stochastic elements to capture variability in outbreak scenarios and trade responses.

Section 4 presents comparative simulations of West Africa and the United States, analyzing how differing tariff policies and disease control capacities influence outcomes under stress conditions. Section 5 discusses the broader implications of these findings for global food security governance and regional trade agreements. The article concludes in Section 6 by identifying policy pathways that enhance resilience, drawing on the comparative insights developed.

Through this structure, the study systematically bridges theory, modeling, and policy analysis to generate actionable recommendations for policymakers.

2. Conceptual framework and literature insights

2.1. Agricultural Trade and Tariff Regimes

Agricultural trade is a critical mechanism for balancing surpluses and deficits across regions, but its structure is deeply shaped by tariff regimes and trade policy frameworks. Tariffs serve as instruments of protectionism, designed to shield domestic producers from foreign competition, yet they can also undermine affordability for consumers by raising import prices [9]. The global debate over liberalization versus protectionism highlights this duality: while trade liberalization can enhance efficiency and expand consumer choice, it often threatens the livelihoods of small-scale farmers who cannot compete with subsidized imports [12].

Protectionist tariffs remain particularly contentious in staple food sectors such as rice, wheat, and maize, where price fluctuations have immediate effects on food access. For instance, export restrictions during the 2007–2008 global food price crisis amplified price spikes worldwide, disproportionately affecting low-income households in food-importing countries [6]. By contrast, liberalized regimes in regions with strong safety nets, such as the European Union, tend to mitigate these impacts through subsidies and redistribution mechanisms.

Tariff regimes also affect competitiveness by shaping incentives for innovation and investment in domestic agriculture. High tariffs may protect vulnerable producers in the short term, but they can discourage efficiency improvements and restrict exposure to global best practices [10]. Conversely, overly liberalized regimes risk dependency on external markets, leaving economies exposed to external shocks and geopolitical tensions [13].

Thus, tariff structures function as both protective barriers and potential sources of vulnerability. The balance between affordability, competitiveness, and resilience remains at the heart of the agricultural trade debate, underscoring the importance of designing flexible, context-specific policies that adapt to shifting global conditions.

2.2. Animal Disease Risks and Food System Shocks

Animal disease outbreaks pose significant risks to food systems, often causing cascading shocks that affect both supply and trade. Highly pathogenic avian influenza (HPAI), for example, has triggered mass poultry culling, market disruptions, and international trade bans, reducing protein availability and destabilizing producer incomes [7]. Similarly, African swine fever (ASF) outbreaks in Asia and Africa have devastated pig populations, leading to price surges and substitution pressures on other protein sources [11].

These outbreaks illustrate the epidemiological and economic intersections of disease risks. On the epidemiological side, factors such as inadequate biosecurity, high-density farming, and porous borders enable rapid disease spread [12]. Economically, outbreaks trigger immediate supply shortages, followed by broader ripple effects in employment, trade balances, and consumer purchasing power [8]. For instance, the ASF epidemic in China reduced the global pork supply, pushing importers to seek alternatives and intensifying competition for limited resources [6].

Regional vulnerabilities further compound these risks. West Africa, where livestock markets often operate informally and veterinary infrastructure remains underdeveloped, faces particular exposure to disease-induced shocks [13]. In such contexts, border closures in response to outbreaks can disrupt informal trade routes that millions of households depend on for protein access and income generation [9]. By contrast, the United States possesses more robust surveillance and compensation systems, yet still experiences significant economic losses when outbreaks occur, underscoring the universal relevance of disease resilience [10].

The complex interplay of epidemiological spread and economic transmission highlights why disease risks cannot be addressed solely through veterinary interventions. Instead, integrated frameworks are required, linking animal health, trade governance, and household food security outcomes.

2.3. Food Security as a Multi-Dimensional Concept

Food security is widely understood as a multi-dimensional concept encompassing availability, access, utilization, and stability. Each dimension is shaped by the interactions between trade systems and disease risks, which can either reinforce or undermine resilience [14].

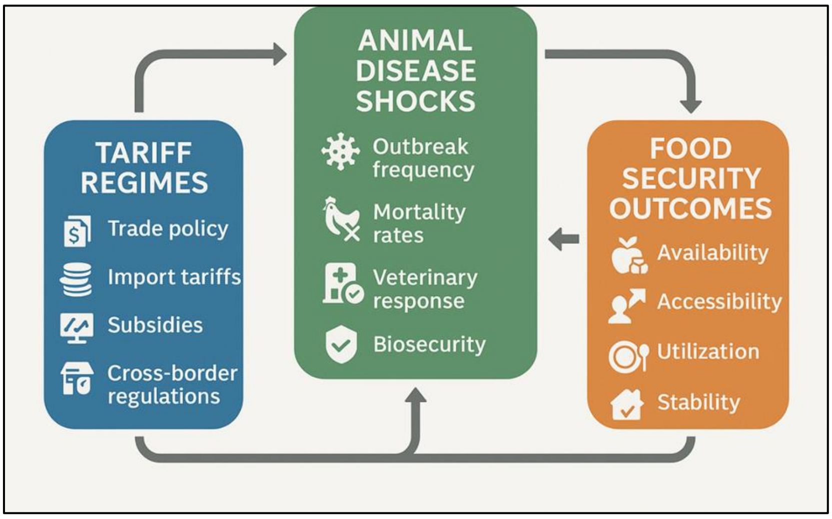

Figure 1 The conceptual framework connecting tariff regimes, animal disease shocks, and food security outcomes across these dimensions

Availability refers to the physical supply of food. Tariffs that restrict imports during crises can reduce availability, while animal diseases reduce production capacity through livestock losses [6]. Access, defined as households' ability to acquire sufficient food, is often constrained when tariffs elevate prices or when disease outbreaks trigger sharp inflation in protein markets [11]. These dynamics are especially acute for low-income households in import-dependent regions [8].

Utilization, the nutritional and health dimension of food security, is also affected. When households shift from diverse diets to cheaper, less nutritious staples due to tariff-induced price hikes, nutritional outcomes deteriorate [12]. Similarly, protein shortages during disease outbreaks force dietary compromises that undermine long-term health and productivity [9].

Finally, stability captures the reliability of food access over time. Both tariff volatility and disease unpredictability create instability, with repeated shocks eroding coping mechanisms and household resilience [13]. In West Africa, recurrent disease outbreaks and inconsistent tariff enforcement exacerbate this instability, while in the United States, trade disputes and biosecurity challenges illustrate that stability remains fragile even in advanced systems [7].

By linking these four dimensions, the analysis demonstrates that food security cannot be treated as an isolated agricultural issue. Instead, it is embedded in broader systems of trade and animal health governance, requiring policies that simultaneously account for economic, epidemiological, and nutritional considerations (see Figure 1).

3. Comparative agricultural systems: west Africa VS. U.S.

3.1. Structure of West African Agricultural Systems

Agricultural systems in West Africa are predominantly smallholder-based, with the majority of farms operated on less than two hectares [14]. These smallholders contribute the bulk of staple food production, including maize, millet, sorghum, and cassava. Despite their importance, they face significant productivity constraints due to limited access to irrigation, improved seed varieties, and credit facilities [16]. The heavy reliance on rainfall further exposes production to climate variability, reinforcing the vulnerability of rural livelihoods.

A defining feature of the region is the prominence of informal trade networks. Livestock and crop commodities frequently cross porous borders through unofficial channels, bypassing tariffs but also escaping veterinary surveillance and sanitary controls [12]. These informal markets play a dual role: they enhance food access and affordability for low-income consumers, yet they heighten exposure to transboundary animal diseases and price instability [15]. For example, cattle trade routes across Mali, Niger, and Nigeria are critical for protein supply, but disease outbreaks such as foot-and-mouth disease often spread rapidly along these corridors.

West Africa also remains reliant on imports for key commodities. Rice imports are especially significant, with countries like Nigeria and Senegal depending on global markets to meet urban demand [18]. This reliance exposes consumers to international price fluctuations, particularly when global tariff disputes or export restrictions occur. Domestic poultry production, although expanding, struggles to compete with frozen poultry imports from Europe and Brazil, despite government protectionist measures [13].

Overall, West Africa's agricultural structure is characterized by smallholder dominance, informal cross-border trade, and persistent import dependence. These structural traits create a complex mix of resilience and vulnerability, where local networks sustain food access but systemic risks such as tariffs and animal disease shocks repeatedly destabilize the system.

3.2. Structure of U.S. Agricultural Systems

In contrast, the U.S. agricultural system is highly industrialized, capital-intensive, and globally oriented. Large-scale commercial farms dominate, with advanced mechanization, biotechnology adoption, and vertically integrated agribusinesses shaping production and distribution [17]. Economies of scale enable efficiency gains that reduce per-unit costs and support a competitive export profile across commodities such as maize, soybeans, wheat, and meat products.

The livestock and poultry sectors, in particular, are tightly integrated into global markets. The U.S. is among the world's leading exporters of beef, pork, and poultry, with production chains characterized by concentrated processing facilities and sophisticated cold storage networks [12]. High levels of biosecurity, veterinary oversight, and government-backed insurance programs help mitigate disease risks, though outbreaks such as avian influenza have nonetheless caused multi-billion-dollar losses [14].

Capital intensity defines the sector. Precision agriculture technologies, including GPS-guided equipment, drones, and data-driven analytics, optimize inputs and enhance yields. Biotechnology adoption, particularly genetically modified crops, further strengthens productivity, contributing to surpluses that support global trade competitiveness [16].

At the same time, the U.S. system is shaped by extensive federal support. Subsidies, crop insurance programs, and international trade negotiations all buffer producers from shocks and maintain market stability [15]. However, this system's global exposure carries inherent risks: tariff disputes, such as the U.S.-China trade conflict, revealed the vulnerability of U.S. soybean exports to retaliatory measures, with ripple effects across rural communities [18].

Thus, the U.S. agricultural system represents a structurally distinct model compared to West Africa: industrialized, export-driven, and heavily capitalized. While resilient in terms of productivity and disease control, its deep integration into global markets leaves it vulnerable to policy disputes and international demand shifts.

3.3. Cross-Regional Contrasts

The comparison between West Africa and the United States reveals sharp contrasts in scale, technology adoption, and exposure to risks. In West Africa, agriculture remains labor-intensive, with minimal mechanization and widespread reliance on informal markets [13]. By contrast, the U.S. system is technologically advanced, deploying capital-intensive machinery and biotechnology to sustain large-scale commercial farms [16].

Trade structures also diverge significantly. West African systems rely heavily on imports for key staples, creating vulnerability to tariff changes and global price swings [12]. In contrast, the U.S. is a major net exporter, leveraging its production surpluses to influence global market dynamics [17]. This exporter profile strengthens its global bargaining power but exposes it to retaliatory tariffs and shifts in international demand.

Risk exposure further illustrates the differences. West Africa's vulnerabilities lie in weak veterinary infrastructure and porous borders that facilitate disease spread through informal trade. The U.S., while better equipped with biosecurity and insurance mechanisms, faces risks from concentrated production and processing systems, where localized outbreaks can have disproportionate impacts [15].

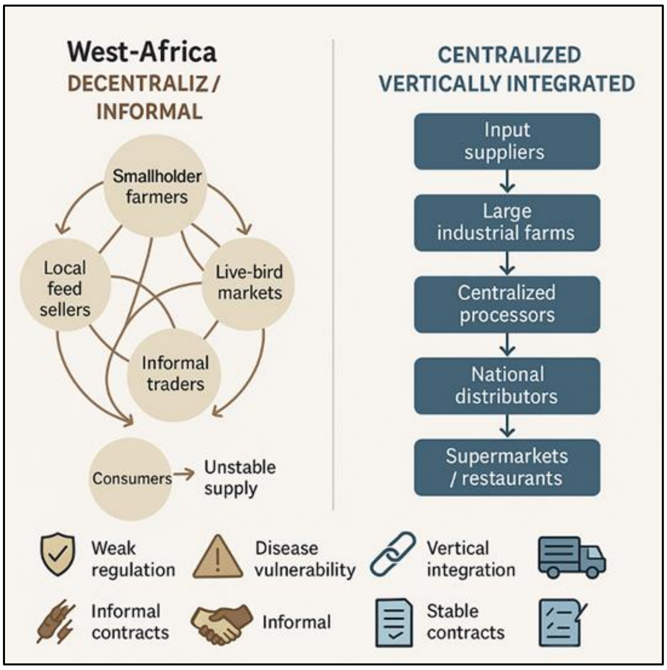

Figure 2 Highlights these structural contrasts in supply chains. The West African poultry and livestock sectors are depicted with decentralized, informal nodes, while the U.S. system is represented by centralized, vertically integrated chains with high regulatory oversight. These stylized diagrams underscore how different organizational logics create distinct resilience profiles

Ultimately, the cross-regional contrasts emphasize the importance of context-specific strategies. While the U.S. must manage risks from global integration, West Africa must address vulnerabilities in informal trade and disease management.

3.4. Simulation Parameters and Assumptions

To examine the effects of tariffs and disease shocks, the simulation framework applies a set of parameters and assumptions that reflect the structural differences between West Africa and the United States. Table 1 summarizes these contrasts, providing a structured basis for the modeling exercise.

For tariffs, West Africa is modeled with variable import duties on poultry and rice, reflecting inconsistent enforcement and regional bloc differences [18]. In the U.S. case, tariff regimes are modeled as stable but subject to retaliatory shocks, such as those observed during trade disputes with China [12]. These assumptions allow the simulation to capture both volatility in developing regions and structured but high-impact disputes in developed economies.

For disease shocks, West Africa's parameters incorporate higher baseline probabilities of outbreak, weak veterinary capacity, and delayed response mechanisms [14]. Informal trade routes are assumed to accelerate disease spread. Conversely, the U.S. simulation incorporates lower baseline probabilities of outbreak, but with concentrated supply chains that magnify local shocks into systemic risks [16].

Economic impacts are modeled through price, availability, and income effects. In West Africa, the simulation emphasizes household-level affordability and protein access, while in the U.S. case, the focus is on producer income stability and export competitiveness [13].

By structuring the simulation around these assumptions, the analysis highlights how tariffs and disease shocks interact differently depending on systemic structures. Table 1 provides a concise overview of these baseline differences, grounding the comparative modeling exercise in empirical realities.

Table 1 Structural differences in agricultural systems: West Africa vs. U.S.

Dimension	West Africa	United States
Farm Structure	Smallholder-dominated; majority under 2 hectares	Large-scale, industrialized, highly mechanized farms
Trade Orientation	Import-dependent for staples (e.g., rice, poultry); heavy reliance on informal cross-border trade	Net exporter of grains, meat, and processed commodities; globally integrated
Technology Use	Low mechanization; limited irrigation; minimal biotechnology adoption	High mechanization; advanced precision agriculture; extensive biotechnology use
Veterinary & Biosecurity	Weak infrastructure; limited surveillance; porous borders	Strong veterinary systems; high biosecurity standards; federal oversight
Market Systems	Informal, decentralized networks; price volatility common	Vertically integrated agribusinesses; stable price mechanisms
Tariff Regimes	Variable enforcement; regional bloc inconsistencies	Stable, rules-based; exposure to retaliatory tariffs in disputes
Resilience Profile	Vulnerable to disease shocks and global price swings; limited safety nets	Strong domestic consumer protection; vulnerable to export losses in global crises

4. Simulation results: tariff policy scenarios

4.1. Baseline Scenario

The baseline scenario assumes normal trade flows under a disease-free environment, providing a reference point for comparative analysis. In this setting, West Africa's agricultural systems remain dependent on rice and poultry imports, with regional integration through the Economic Community of West African States (ECOWAS) shaping tariff alignment [21]. Informal cross-border trade plays a major role, mitigating localized supply deficits and smoothing consumption patterns. However, price transmission from global markets is high, meaning that fluctuations in world prices directly impact urban consumers [18].

For the United States, the baseline reflects an export-oriented system with strong disease surveillance and relatively stable tariff structures. Grain exports, particularly maize and soybeans, dominate trade balances, while livestock exports continue to expand in Asian and Latin American markets [22]. Domestic prices remain relatively stable due to subsidies, crop insurance, and government intervention mechanisms, limiting consumer exposure to external volatility [19].

In both regions, the absence of disease shocks creates conditions of relative stability. Availability remains consistent in the U.S., whereas in West Africa it depends on continuous access to external markets. Affordability remains a persistent concern in West Africa due to structural import reliance, while in the U.S., competitive surpluses anchor food prices at affordable levels [17].

This baseline highlights systemic contrasts: West Africa's exposure stems from external dependencies, while the U.S. system relies on global integration but is shielded by strong institutional buffers. It provides a neutral benchmark against which high-tariff and liberalization simulations can be assessed.

4.2. High Tariff Scenario

The high tariff scenario models the imposition of protective tariffs in West Africa, particularly on poultry and rice, reflecting policy shifts toward shielding domestic producers. These measures aim to encourage local production and reduce import dependence. However, the short-term effects are adverse. Import volumes fall sharply, urban food prices rise, and affordability for low-income households declines [23]. Informal markets partially fill the gap, but these remain insufficient to stabilize supply, particularly when urban demand outpaces local production capacity [20].

Trade diversion emerges as a key outcome. With tariffs raised, consumers shift toward alternative imports from non-traditional partners, often at higher prices. Poultry imports from Brazil and rice from Asia become more costly, amplifying pressure on household budgets [18]. Local producers gain some advantage, but structural constraints—low mechanization, limited feed availability, and high disease risks—prevent them from meeting surging demand [21]. As a result, food security deteriorates, especially in terms of access and stability.

In the United States, a high tariff scenario is modeled differently. Here, tariffs are considered as retaliatory measures imposed by trading partners, as in the U.S.–China soybean dispute. Export revenues decline, farm incomes fall, and government subsidies expand to cushion producers [24]. Domestic consumers remain relatively insulated, as tariffs target exports rather than imports, but rural economies face significant hardship.

Thus, while high tariffs in West Africa reduce consumer access to food, in the U.S. they primarily reduce producer competitiveness. This divergence illustrates the asymmetric effects of tariffs across structurally different agricultural systems.

4.3. Liberalization Scenario

The liberalization scenario explores reduced tariffs in both West Africa and the U.S., reflecting policies aimed at enhancing integration into global markets. In West Africa, lowering tariffs on rice and poultry improves affordability by expanding access to cheaper imports [19]. Urban consumers benefit immediately from declining food prices, while informal markets continue to play a role in distribution. However, the surge in imports undermines local producers, who face intensified competition from subsidized exports [17]. Over the long term, this can erode incentives for investment in domestic agriculture, perpetuating structural dependence.

For the United States, liberalization consolidates its export advantage. Reduced barriers in target markets stimulate demand for U.S. grains and meats, bolstering farm incomes and reinforcing its status as a global agricultural powerhouse [22]. The gains are magnified by technological advantages and economies of scale, which enable U.S. producers to compete effectively even in liberalized contexts [20].

Price effects differ across regions. In West Africa, liberalization enhances affordability but exacerbates vulnerability to global shocks. In the U.S., liberalization reinforces competitiveness but increases exposure to fluctuations in global demand. Both systems experience benefits and risks, though their structural foundations lead to divergent long-term outcomes [23].

This scenario underscores the trade-off between short-term consumer welfare and long-term production sustainability in West Africa, while in the U.S., the key challenge lies in balancing export growth with resilience against external demand shocks.

4.4. Comparative Implications

The comparative results reveal profound asymmetries in how tariffs shape food systems. In West Africa, protective tariffs exacerbate consumer hardship by raising food prices, while liberalization lowers prices but entrenches structural dependence on imports [18]. Disease-free assumptions amplify these effects, as outbreaks would further magnify vulnerabilities.

In the United States, tariff impacts are filtered through its role as a global exporter. High tariffs, usually imposed externally, reduce producer competitiveness and farm incomes, while liberalization strengthens its export profile but heightens reliance on volatile global markets [21]. Domestic consumers remain largely insulated in both scenarios due to institutional buffers and subsidy frameworks [19].

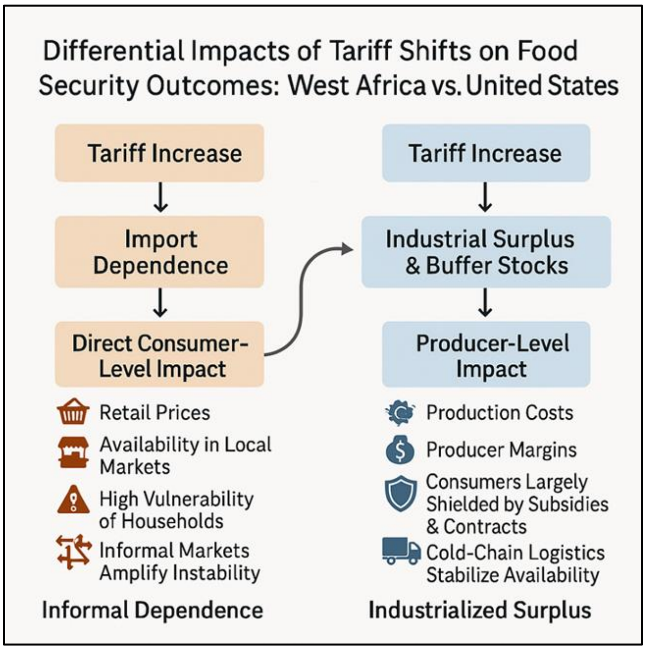

Figure 3 Illustrates these contrasts, showing how tariff shifts drive price and availability outcomes differently across regions. West Africa experiences direct consumer-level impacts, while the U.S. absorbs producer-level shocks. The structural foundations of each system informal dependence versus industrialized surplus explain these divergent patterns [24]

Ultimately, the analysis highlights that tariff interventions cannot be evaluated uniformly across contexts. Policymakers must account for systemic structures, as identical policy tools generate distinct and asymmetric consequences for food security and agricultural resilience.

5. Simulation results: Animal disease shock scenarios

5.1. West African Disease Shock

In West Africa, avian influenza outbreaks represent one of the most disruptive shocks to the regional food system. Poultry is a key source of affordable protein, particularly in urban centers, and outbreaks quickly undermine both supply and livelihoods [26]. Smallholders, who dominate poultry production, often lack access to veterinary services, compensation schemes, or biosecure housing systems, leaving them highly vulnerable to disease-driven losses [22].

When avian influenza spreads, culling programs are implemented inconsistently due to resource constraints and governance gaps, resulting in uneven containment [27]. The collapse of local supply forces consumers to rely more heavily on imports of frozen poultry, often at higher prices, straining household budgets. This dynamic exacerbates existing import dependence, creating further exposure to global market volatility [24].

Smallholders experience disproportionate impacts. Beyond the immediate loss of flocks, disease shocks reduce income from poultry sales, erode household resilience, and push families deeper into poverty [25]. Informal traders are also affected, as border closures disrupt cross-border supply chains that typically sustain regional protein markets. These disruptions highlight how animal disease shocks in West Africa extend beyond public health, reverberating across economic, social, and nutritional domains [28].

Thus, avian influenza in West Africa demonstrates the fragility of smallholder-dominated systems under disease stress. The interaction of weak veterinary infrastructure, reliance on informal markets, and heavy import dependence amplifies the severity of food security challenges during such outbreaks.

5.2. U.S. Disease Shock

In the United States, disease shocks such as swine fever or avian influenza have markedly different dynamics, reflecting the industrialized, globally integrated nature of the system. Large-scale production facilities, while more biosecure, also carry systemic risks when outbreaks occur. The 2015 avian influenza epidemic, for example, led to the destruction of over 50 million birds and cost the economy billions of dollars in losses [23].

Containment mechanisms are stronger than in West Africa, with federal and state agencies implementing rapid surveillance, culling, and compensation programs [27]. These measures stabilize farmer incomes, but they cannot prevent temporary disruptions in supply chains. The scale of U.S. exports amplifies the global impact: when domestic outbreaks occur, importing countries often impose bans, reducing international supply and driving up global prices [22].

Swine fever scenarios demonstrate similar ripple effects. Even in the absence of confirmed U.S. outbreaks, the global pork market reacts to fears of spread, causing price volatility. Producers face reduced export demand, while domestic consumers are largely insulated due to substitution with alternative proteins [26].

The resilience of the U.S. system lies in its financial and institutional buffers, which protect domestic consumers and producers from catastrophic outcomes. However, the global food system bears the costs of lost exports, price spikes, and resource diversion [28]. This contrast highlights how U.S. disease shocks resonate internationally, underscoring the interconnected nature of industrialized agricultural trade and global food security [25].

5.3. Cross-Regional Comparative Effects

Comparing disease shocks across West Africa and the United States reveals significant asymmetries in scale, containment capacity, and resilience. In West Africa, outbreaks spread quickly due to porous borders, weak veterinary oversight, and reliance on informal trade channels [24]. The result is deep and prolonged supply shortages that directly compromise household food access. By contrast, in the U.S., outbreaks are generally localized and swiftly contained, but the economic losses are far greater in absolute terms due to the scale of industrial production [27].

Containment capacity also diverges. The U.S. has institutionalized compensation schemes and surveillance, while West Africa struggles with delayed responses and resource constraints [22]. Resilience is therefore structurally uneven: U.S. consumers experience minimal food insecurity impacts, whereas West African households face acute affordability and nutritional crises [26]. This comparative analysis underscores how disease shocks translate into vastly different consequences across agricultural systems.

5.4. Food Security Outcomes

The food security implications of disease shocks are multidimensional, affecting availability, access, utilization, and stability. In West Africa, avian influenza outbreaks reduce availability through poultry losses and border closures, restrict access by raising prices, and undermine utilization by forcing households to shift to less nutritious diets [28]. Stability is compromised as repeated outbreaks erode coping strategies and trust in local production systems [25].

In the United States, availability is temporarily reduced during culling events, but imports and substitution quickly stabilize supply [23]. Access remains largely unaffected due to robust subsidies and insurance mechanisms, while utilization is minimally influenced as dietary options remain diverse [22]. Stability is threatened only at the global level, where trade bans and price volatility ripple across importing countries [26].

Table 2 summarizes these outcomes, contrasting the severity and scope of food security effects across the two regions. This comparative framing highlights both the structural vulnerabilities of smallholder systems and the global consequences of industrialized disruptions.

Table 2 Comparative food security outcomes under simulated disease shocks

Food Security Dimension	West Africa (Avian Influenza Shock)	United States (Swine Fever/Avian Influenza Shock)
Availability	Severe reductions in poultry supply due to culling; border closures restrict imports; reliance on external markets deepens shortages.	Temporary supply reductions from culling; domestic substitution with alternative proteins maintains overall availability.
Access	Significant decline in affordability as prices rise; vulnerable households hardest hit; informal trade disruptions limit local access.	Minimal consumer impact; government subsidies and insurance stabilize prices; impacts concentrated on producers/exporters.
Utilization	Shift to less nutritious staples when protein becomes unaffordable; long-term dietary compromises undermine nutrition.	Limited impact on dietary quality; consumers maintain diverse diets through substitution options.
Stability	Repeated outbreaks erode household resilience; fragile informal markets amplify instability; long-term trust in local systems declines.	Domestic stability maintained; instability felt globally through export bans, trade restrictions, and price volatility.

6. Integrated policy simulations: tariff + disease risks

6.1. Combined Shock Scenarios

When tariff policies and animal disease risks are considered together, their interactions amplify vulnerabilities in both West Africa and the United States. The combined shock scenario overlays trade barriers with epidemic disruptions, producing outcomes more severe than either shock alone [27]. In West Africa, protective tariffs imposed to shield domestic producers collide with avian influenza outbreaks that decimate poultry flocks, creating dual constraints on supply. Imports become more costly due to tariffs, while domestic availability collapses due to disease-induced culling [29].

These pressures reverberate through informal trade systems, which typically cushion supply shortages but cannot function effectively when borders are closed during health crises. As a result, protein availability plunges and household affordability declines sharply [26].

In the United States, combined shocks manifest differently. Tariff disputes that restrict export flows interact with disease outbreaks such as avian influenza or swine fever, compounding economic losses for producers [30]. Exports collapse due to both foreign restrictions and domestic containment measures, creating a dual hit to revenues. While U.S. consumers remain insulated, global food systems absorb the ripple effects, experiencing scarcity and price hikes.

The combined scenario highlights the non-linear nature of agricultural risks: when tariffs and diseases coincide, they create compounding shocks that stretch institutional and market coping capacities, undermining resilience across both developed and developing systems [32].

6.2. Differential Impacts on West Africa

The impact of combined shocks in West Africa is magnified by the region's structural reliance on imports and informal trade networks. Tariff-induced restrictions raise the cost of rice and poultry imports, while concurrent disease outbreaks devastate domestic poultry stocks. This dual exposure translates into immediate reductions in food availability and affordability [31].

Households already vulnerable to food insecurity face severe access challenges, as rising prices outpace income growth. Informal cross-border markets, often the safety valve for regional food systems, collapse under the weight of border closures and veterinary restrictions [28]. The result is not only a decline in protein access but also a broader destabilization of regional food supply chains.

Smallholders, who form the backbone of local production, experience compounding losses. Disease shocks reduce flock sizes, while tariffs distort market incentives by elevating consumer demand for imports that are simultaneously restricted [26]. The absence of robust compensation mechanisms leaves rural households with little recourse, eroding long-term resilience.

Over time, combined shocks exacerbate structural dependence on imports. Consumers turn to international suppliers at higher prices, deepening vulnerability to external volatility [29]. These dynamics highlight how layered shocks interact with weak governance and underdeveloped infrastructure to push households into prolonged cycles of insecurity.

For West Africa, combined shocks underscore the fragility of informal systems and demonstrate how simultaneous tariff and disease disruptions amplify vulnerabilities across every food security dimension.

6.3. Differential Impacts on U.S.

In the United States, the interaction of tariffs and disease outbreaks produces significant but distinct outcomes, reflecting the system's global export orientation and institutional capacity. Tariff disputes, such as those involving China, already reduce export revenues and alter trade flows [26]. When layered with animal disease outbreaks, these effects intensify, producing both domestic and international consequences.

For producers, the combination of export restrictions and disease-driven supply disruptions results in income shocks that exceed those from either factor alone [30]. Large agribusinesses often mitigate losses through insurance schemes and federal compensation programs, but small and medium-sized farms remain vulnerable, particularly in livestock sectors [27].

Global markets bear the brunt of combined shocks. When U.S. poultry or pork exports are curtailed due to disease outbreaks, importing countries face scarcity, while tariffs prevent rapid substitution. Price volatility spreads globally, with developing countries most affected due to limited fiscal capacity to absorb higher costs [32].

Domestically, however, consumer access remains relatively stable. Government interventions, diversified protein sources, and integrated logistics networks buffer households from major disruptions [33]. The primary consequence lies in lost competitiveness and diminished export share, as importing nations pivot toward alternative suppliers.

Thus, the U.S. demonstrates resilience at the consumer level but vulnerability at the global market level. Combined shocks highlight the paradox of industrialized agriculture: robust buffers shield domestic systems, but ripple effects destabilize international markets and trading partners.

6.4. Policy Sensitivity Analysis

Policy sensitivity analysis under combined shocks reveals trade-offs between short-term protection and long-term resilience. In West Africa, imposing tariffs during disease outbreaks amplifies consumer hardship. Reducing tariffs could ease access to imports, but risks undermining domestic producers and deepening structural dependence [29]. Policy responses must therefore navigate between protecting smallholders and ensuring affordability for urban consumers [28].

For the United States, the analysis shows that tariffs primarily reshape export markets, while disease outbreaks disrupt supply capacity. Combined, they create severe revenue losses. Adjusting tariffs downward during outbreaks may soften impacts on global partners but risks exposing U.S. producers to competition in already unstable conditions [30]. Compensation schemes alleviate some domestic pressures but cannot prevent the erosion of export market share [26].

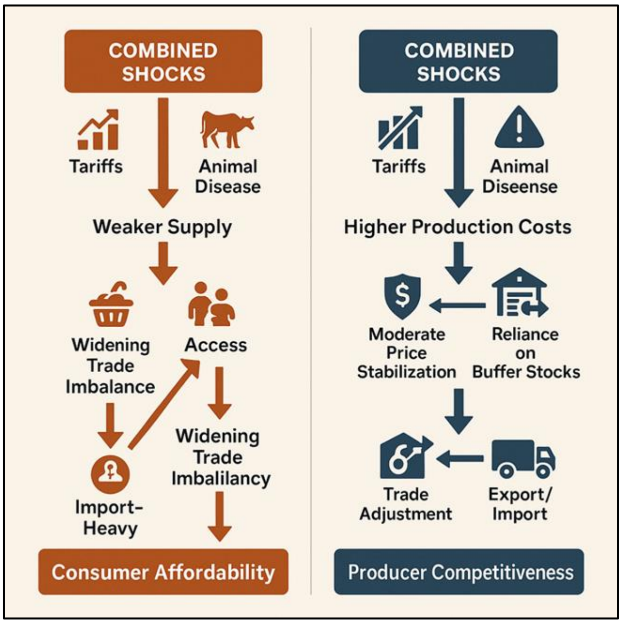

Figure 4 Illustrates these dynamics, showing how policy adjustments alter outcomes across availability, access, and trade balances under combined shocks. The figure highlights the asymmetry: West Africa's outcomes hinge on consumer affordability, while the U.S. outcomes hinge on producer competitiveness [33]

Sensitivity analysis underscores the importance of flexible, adaptive policies. In West Africa, strategies that combine tariff moderation with targeted producer support could mitigate both affordability and resilience challenges [31]. In the U.S., diversification of export destinations and strengthening global biosecurity cooperation may reduce the magnitude of losses under combined risks [27].

Ultimately, policy tools must account for systemic differences: while the same shocks affect both regions, the pathways of impact diverge sharply, demanding tailored interventions.

7. Discussion

7.1. Key Insights from Comparative Simulations

The comparative simulations reveal several important insights into the interplay between tariffs, disease risks, and resilience across agricultural systems. First, tariffs shape the distribution of risk differently in West Africa and the United States. In West Africa, protective tariffs exacerbate consumer hardship by elevating food prices during disease shocks, while liberalization lowers prices but entrenches dependency on imports [33]. In the U.S., tariffs primarily affect producer revenues, with global ripple effects when exports decline, yet consumers remain largely shielded through subsidies and diversified supply chains [31].

Second, disease risks interact with tariff regimes to create compounding effects. In West Africa, avian influenza outbreaks combined with tariffs reduce both domestic availability and import access, magnifying food insecurity [37]. In the U.S., similar disease shocks lead to export bans and revenue declines, but institutional buffers prevent major domestic shortages. These contrasts highlight how systemic structures determine which populations bear the brunt of shocks [32].

Third, resilience dynamics diverge. West Africa demonstrates fragility due to informal trade reliance, weak veterinary systems, and high import dependence. Meanwhile, the U.S. exhibits strong consumer resilience but remains vulnerable to global reputational losses and trade displacement when disease outbreaks occur [35].

Overall, the simulations illustrate that identical shocks have asymmetric impacts, shaped by structural differences in scale, technology, and governance. Understanding these dynamics is crucial for designing policies that not only address immediate crises but also strengthen long-term resilience across diverse agricultural systems [38].

7.2. Implications for Trade Policy

The findings underscore critical implications for trade policy in both regional and global contexts. For West Africa, reliance on informal trade and import dependence creates a need for flexible tariff regimes that balance consumer affordability with producer incentives [31]. Protective tariffs may stabilize domestic markets in the short term, but when combined with disease shocks, they exacerbate shortages and undermine access [34].

Regional negotiations within blocs such as ECOWAS must therefore prioritize harmonized tariff frameworks that account for both consumer and producer vulnerabilities. Coordination can reduce policy fragmentation, enhance market predictability, and improve collective resilience to shocks [36]. At the same time, targeted producer support such as subsidies or veterinary programs can complement tariff moderation, reducing the risk of dependency while protecting rural livelihoods [32].

In the United States, trade policy implications revolve around its role in global markets. Tariff disputes often lead to retaliatory measures that erode competitiveness, as seen in soybean and pork markets [35]. Balancing national protection with compliance under World Trade Organization (WTO) rules remains central. Excessive protectionism risks violating global trade commitments, while over-liberalization leaves producers exposed during global downturns [33].

Thus, both regions face a trade-off between safeguarding national interests and sustaining global integration. The challenge lies in crafting policies that are adaptive to crises yet aligned with international obligations. This requires balancing domestic protection, regional cooperation, and global market stability.

7.3. Implications for Food Security Policy

The simulations also provide important lessons for food security policy, particularly under compound shocks. In West Africa, tariffs layered with disease outbreaks reduce availability by cutting off imports and depleting domestic production. Access is constrained as prices rise, while stability declines due to the frequency and severity of shocks [38]. Food security strategies must therefore address both affordability for consumers and resilience for smallholder producers [34]. This may involve investment in veterinary infrastructure, targeted food subsidies, and safety nets for vulnerable households.

In the U.S., food security outcomes are less severe but remain important. Disease outbreaks primarily disrupt exports, but domestic stability is maintained through insurance and federal interventions [31]. Policies should continue to reinforce these buffers while recognizing the global consequences of export reductions. When U.S. supply is disrupted, global importing nations many in the Global South face sharp price increases, creating external food insecurity pressures [37].

Therefore, food security policy cannot be viewed in isolation at the national level. In both regions, policies must be designed to integrate with trade frameworks and global market dynamics. West Africa requires mechanisms to reduce dependency while ensuring affordable access, whereas the U.S. must manage the global spillovers of its system's disruptions [35].

Ultimately, compound shocks illustrate that food security policies must be multidimensional, incorporating availability, access, utilization, and stability across both short- and long-term horizons [32].

7.4. Role of International Cooperation

International cooperation emerges as a central pillar for addressing the asymmetric risks revealed in the simulations. Joint disease surveillance systems are particularly critical, as early detection and coordinated response can reduce the severity of outbreaks in both developing and developed contexts [33]. Regional mechanisms in West Africa require greater investment, while U.S. participation in global networks ensures the timely exchange of data and containment practices [36].

Trade harmonization also plays a vital role. Harmonized sanitary standards, tariff coordination, and crisis-management protocols reduce uncertainty and facilitate smoother recovery after shocks [31]. For West Africa, harmonization within ECOWAS could limit policy fragmentation, while U.S. engagement in WTO and bilateral negotiations remains essential for stabilizing global supply chains [38].

The combined shock scenarios demonstrate that no country is insulated from interconnected risks. Disease outbreaks in one region reverberate globally, while tariff disputes disrupt food flows across continents [37]. Coordinated strategies ranging from joint surveillance to harmonized tariff responses offer pathways to build resilience collectively[39].

International cooperation, therefore, is not a matter of choice but of necessity. Without it, both West Africa and the United States will continue to face heightened vulnerabilities under compound crises [40].

8. Conclusion

8.1. Summary of Findings

The simulations and comparative analysis underscore the complexity of agricultural trade and food security under interacting tariff and disease shocks. West Africa's systems, dominated by smallholders and informal trade, reveal heightened vulnerability when protective tariffs and avian influenza outbreaks occur simultaneously. Tariffs restrict imports just as disease depletes domestic supply, creating severe affordability challenges. Conversely, liberalization lowers food prices but entrenches long-term dependence on external markets.

The U.S. system demonstrates contrasting dynamics. Its industrialized, export-oriented profile shields domestic consumers through insurance schemes, subsidies, and diversified supply chains. Yet, when tariffs and disease outbreaks coincide, producers face sharp income losses, and global ripple effects destabilize international food markets. Disease shocks in the U.S. therefore carry global consequences, while in West Africa they primarily erode local resilience and household security.

Overall, the findings highlight that identical shocks produce divergent outcomes depending on structural context. West Africa's fragility lies in dependency and weak veterinary systems, while the U.S. exhibits resilience domestically but generates volatility internationally. These asymmetries reveal that food security outcomes are not only about production levels but also about the interplay of governance, trade policy, and systemic resilience mechanisms.

8.2. Recommendations for Policymakers

For West Africa, policymakers should prioritize reducing structural dependence on imports while strengthening resilience in smallholder and informal systems. This requires coordinated tariff policies across regional blocs, investments in veterinary infrastructure, and targeted support for smallholders to increase productivity and disease preparedness. Food subsidies and social protection programs should be designed to shield vulnerable consumers during crises, ensuring affordability without undermining domestic production incentives.

In the U.S., policymakers should focus on balancing domestic protection with global responsibilities. Diversifying export markets, strengthening multilateral trade cooperation, and investing in global disease surveillance partnerships will mitigate the international ripple effects of domestic shocks. Federal programs should continue to cushion producers, but complementary efforts must be made to minimize negative spillovers on global food security.

At the intersection of trade and disease risk, both regions must adopt adaptive policies that anticipate compounding shocks. Flexible tariff frameworks, crisis-specific import rules, and regional disease surveillance systems can strengthen resilience. Collaborative international mechanisms, such as harmonized sanitary standards and rapid response protocols, are equally essential.

Ultimately, policy design should move beyond short-term crisis management toward building durable resilience, integrating trade policy with health and food security strategies at both regional and global levels.

8.3. Final Reflections

The analysis demonstrates that food system resilience is deeply intertwined with trade policies, disease risks, and global interdependence. West Africa and the United States, though structurally distinct, illustrate how vulnerabilities manifest differently but remain connected through international markets. Addressing these challenges requires not only national reforms but also global solidarity, where cooperation in disease surveillance, trade harmonization, and equitable policy frameworks becomes a shared priority. Strengthening resilience across regions is not merely a technical task but a moral imperative, ensuring that all populations regardless of geography can access stable, affordable, and nutritious food systems in an increasingly uncertain world.

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