A Formal Framework for Measuring Institutional Collapse under a Nuclear Winter Scenario

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September 2026

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September 16, 2026

Abstract

A medium-scale regional nuclear exchange could plausibly loft $\sim$16 Tg of soot into the stratosphere, sufficient to reduce conventional agricultural output past the $\sim$30% threshold at which large-scale starvation emerges. Alternative food-production methods could restore sufficient caloric supply in the United States, but scaling them to $\sim$70% of pre-shock capacity requires at least 12 months. This creates a critical 6–12 month bridge during which survival depends on existing food stocks, rapid diversion of calories, and the continued functioning of the institutions that enable their distribution.

We argue that this bridge is a problem not only of aggregate food availability but also of economic and political coordination. A severe food shock could either result from or exacerbate institutional collapse, or conversely, institutional deterioration could severely compromise food distribution, among other things. Although nuclear winter's consequences for agriculture have received substantial attention, comparatively little work has examined such a scenario's impact on the potential breakdown of certain critical economic and political institutions. This research gap is particularly important in light of the survival of populations during the first year after a nuclear exchange likely depending less on latent food-production capacity than on whether the institutional mechanisms necessary for allocating existing calories remain functional.

Hence, we suppose that currency stability, as well as viable contract and property-rights enforcement, are necessary for the functioning of a nationwide price mechanism, which is in turn the most efficient means for distributing remaining

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foodstuffs and scaling up the alternative production methods. We seek to model these institutions as tippable coordination equilibria. Doing so produces a quantitative measurement of these institutions' risk of collapse in the wake of a nuclear winter scenario and permits us to define a country-level fragility index based on the distance from the weakest institution to its tipping point. We restrict the analysis to the United States and estimate institutional fragility under two primary scenarios: a regional India–Pakistan exchange, in which the primary shock is soot concentration in the stratosphere, and a U.S.–great-power exchange, in which soot is compounded by direct blast damage to the nation's infrastructure. Our objective is to identify which institution is most likely to collapse first and thereby determine which peacetime investments and policy measures could most cost-effectively preserve economic coordination.

Section 1 - Nuclear Winter Scenarios and the Necessity of Institutions

1.1 Introduction and the Two Scenarios of Interest

Several events with a non-negligible probability of occurrence could plausibly inject a quantity of black carbon (soot) into the atmosphere sufficient to reduce agricultural yields to a level that compromises food security for billions of people across the world. These events include, but are not limited to, a supervolcano eruption, an asteroid or comet impact, or a nuclear winter following a medium- or large-scale nuclear altercation between two warring states (Denkenberger & Pearce, 2014). The latter event's probability is far greater than the previous two, so we'll consider the details of such a scenario and its impact on agricultural production in more depth (Denkenberger & Pearce, 2014; Ord, 2020).

A state-to-state nuclear altercation would be overwhelmingly likely to involve India and Pakistan, the U.S. and China, the U.S. and Russia, or the U.S. acting on its security guarantee to either South Korea or Japan in the wake of a North Korean nuclear attack (Berzak, 2026). Any of the above altercations would likely either involve strikes on countervalue targets or, more generally, any land area possessing a critical mass of combustible material such that the detonations would result in firestorms lofting anywhere between 5 and 150 Teragrams (Tg) of soot into the upper atmosphere, depending on the scale of the altercation (Berzak, 2026; Xia et al., 2022). The total explosive yield required for such a range corresponds to a minimum of $\sim$ 1 Megaton (Mt), or 2-10 strategic nuclear weapons of yield between 100 and 500 kilotons (kt), to $\sim$ 2,000 Mt, or $\sim$5,000 strategic nuclear weapons of the same yield range. It is worth noting that even this upper threshold falls well within both the U.S.'s and Russia's disposable stockpiles (Kristensen & Korda, 2023).

Hence, we will consider two scenarios: a medium-scale regional nuclear altercation between India and Pakistan, and a large-scale great power nuclear altercation that involves the U.S. Within each scenario, we consider three levels of expected soot injection such that six cases are considered in total. For the India–Pakistan scenario, these levels are 5, 13, and 47 Tg, corresponding to a limited countervalue exchange, a broader exchange against major urban centers, and the near-complete deployment of both arsenals against cities or otherwise highly combustible areas, respectively (Toon et al., 2019; Xia et al., 2022). Such a conflict would most plausibly arise from escalation, perhaps a border dispute within Kashmir eventually reaching first-use after conventional engagement, with the passing of each escalatory rung reflecting a failure of intrawar deterrence. Meanwhile, for the great power scenario, the levels are 47, 80, and 115 Tg, corresponding to a limited strategic exchange (relative to the corresponding state capacity), a large-scale countervalue exchange, and near-total deployment of strategic nuclear arsenals (Xia et al., 2022; Kristensen & Korda, 2023). Here, both escalation and confrontation represent plausible pathways. While the former may witness a conventional war involving the U.S. and another great power, with the losing party crossing the nuclear threshold and retaliatory strikes expanding from military to industrial and population targets, the latter may arise through a direct crisis between the U.S. and either Russia or China in which one party faces an intolerable strategic loss and crosses the nuclear threshold outright, with retaliatory strikes expanding damages and soot injection in the same way as mentioned previously (Berzak, 2026). Consider, for instance, a Taiwan crisis in which U.S. intervention threatens to destroy a Chinese landing force, or a Baltic invasion in which Russia faces conventional defeat at the hands of Western powers as a result of NATO's Article V, each generating a loss under which first use may plausibly become rational.

Once injected, soot persists in the stratosphere under a residence half-life of 3 to 7 years, where it absorbs solar radiation, i.e., preventing sunlight from reaching the Earth and subsequently disrupting the hydrological cycle, yielding extreme variability in precipitation (Robock et al., 2007; Coupe et al., 2019). A severe reduction in agricultural yields lasting at least 7 years consequently follows from this Abrupt Sunlight Reduction Scenario (ASRS). Global caloric yields, assuming that no change in production methods occur, could fall between $\sim$ 10% under the 5 Tg scenario to $\sim$ 90% corresponding to 150 Tg, while the country-specific expected reduction depends on both total quantity of soot and geographic proximity to the blast, in terms of both higher soot concentration near blast zones and whether or not the country was involved in the altercation and subsequently suffered a severe reduction in infrastructural (and hence productive) capacity (Xia et al., 2022; Jägermeyr et al., 2020). Dropoffs are expected to be more severe in the Northern Hemisphere, where all of the world's nuclear weapons and countries with an overwhelming probability of becoming the ones involved in a nuclear altercation are located (Xia et al., 2022). Furthermore, soot, like other stratospheric aerosols, naturally tends to migrate towards the poles, meaning that the Northern Hemisphere is ultimately expected to possess a vast majority ($\sim$ 90-95%) of lofted soot in the case of a nuclear winter (Coupe et al., 2019). With 90% of the Earth's arable and fertile land lying north of the

Equator and soybeans being the only critical foodstuff primarily concentrated in the Southern Hemisphere, it is also unlikely that any severely afflicted country could rely on international trade as a long-term solution (Xia et al., 2022; Jehn et al., 2025). Furthermore, the $\sim 30\%$ dropoff in global caloric production threshold, beyond which countries either suffering from or located near the initial blast damage will begin to face starvation, could plausibly follow from as (relatively) small a quantity as 16 Tg of soot, well within the expected range of a regional nuclear conflict (Xia et al., 2022; Hinge et al., 2026). In short, the prospect for much of the world to evade starvation, much less severe nutritional deficits, through purely conventional agriculture is not promising.

1.2 The Viability of Alternative Methods and of Distribution under the Price Mechanism

However, and fortunately for humanity, numerous alterations to conventional agriculture and alternative production methods already exist and only require implementation at scale. The former class (alterations) includes shifting towards crops more resilient to lower temperatures and solar radiation, expanding the cultivation of seaweed and seafood, diverting calories away from animal feed and ethanol production, strategically relocating cropland, as well as expanding cropland availability (Denkenberger & Pearce, 2014; Blouin et al., 2025; Monteiro et al., 2026). All of these strategies, and diversion in particular, are relatively quick to implement and could provide a short-term, partial remedy to the expected dropoff in yields and subsequent food scarcity, effectively buying more time for alternative production methods to scale (Denkenberger & Pearce, 2014; Rivers et al., 2024). This latter class, the methods of food production that operate independently of sunlight, includes lignocellulosic sugar (the conversion of plant biomass such as wood, agricultural residues, or waste paper into edible sugar, and subsequently protein), leaf protein concentrate (edible mass extracted from leaves), microbial single-cell protein (feeding bacteria on substrates such as natural gas or hydrogen), and precision fermentation (uses genetically engineered microorganisms such as yeast or bacteria to produce certain high-purity molecules) (Throup et al., 2022; Anoop et al., 2023; García Martínez et al., 2021, 2022). Crucially, each method listed above requires either the repurposing of remaining industrial capacity in the form of pulp and paper mills, breweries, and power plants or the construction of new facilities (Throup et al., 2022; García Martínez et al., 2022). Operations literature and models produced by ALLFED suggest that even with strong investment in these methods, on the order of hundreds of billions of USD, they could not scale to a level corresponding to 70% of pre-shock caloric production capacity for at least 12 months (Rivers et al., 2024; Denkenberger et al., 2022). Hence, the need for adequate critical goods markets is twofold: to ensure that sufficient investment is directed towards scaling up these alternative methods, and to maintain a viable food distribution network that yields a socially efficient and morally acceptable outcome by minimizing starvation and the cascading risks associated with it both before and after the 12 months during which the alternative methods scale up.

Both the market, integrating exchange between individuals under the price mechanism, and a government, distributing goods via rationing, could technically satisfy this dual requirement. However, if successful, markets would do so at a far lower cost. Specifically, the informational burden associated with maintaining a nationwide rationing network, even for a period as short as several months to no more than a few years, is immense (Hayek, 1945). A central authority must determine who needs what and in what quantity, and continuously revise this allocation in tandem with any change in conditions to achieve the optimal outcome. The U.S. Office of Price Administration (OPA), which was initially established to impose price controls in an attempt to curb the inflation resulting from increased government wartime expenditure during WWII before essentially transforming into a rationing organization, aptly demonstrates the cost of such an endeavor (Mansfield, 1948). Meanwhile, the price mechanism alleviates this burden by compressing dispersed information regarding relative scarcity and needs into a single value that manages to coordinate economic behavior without the need for any centralized direction (Hayek, 1945). Furthermore, the prospect of a governing body effectively seizing foodstuffs, even if guided by the commendable aim of ensuring an equitable distribution of food, leaves little non-coercive incentive for food producers.

Food prices would absolutely increase in the wake of a nuclear winter scenario. In a comprehensive modeling study of the cereal market (i.e., the aggregation of wheat, rice, and maize) under a protracted, multi-year productivity shock, Hinge et al. (2026) find that an injection of $\sim$16 Tg of soot (reducing yields by $\sim$11–23%) is expected to raise equilibrium cereal prices by a factor of $\sim$1.7–1.9$\times$, while a $\sim$47 Tg injection (reducing yields by $\sim$43–52%) is expected to raise equilibrium prices roughly ten- to thirteenfold. Increases of a similar order of magnitude have recurred throughout modern history.

However, could this increase be sufficient to warrant starvation concerns? The vast majority of recent literature focusing on the economics of famine has revolved around Amartya Sen's entitlement theory, first detailed in a proof-of-concept paper focusing on the Bengali Famines of 1943 and 1974 before being further developed and popularized in his 1981 book Poverty and Famines (Sen, 1977, 1981). Arguing against the traditional "Food Availability Decline" (FAD) hypothesis, which asserts that food shortages are the primary cause of famines, Sen proposes that a person's capacity to purchase food and therefore not starve depends on their entitlement set, the vector of bundles of all goods and services that one may acquire in the market using their endowments (the total market value of one's labor power and property) (Sen, 1981). Hence, famines are little else than entitlement failures, emerging when the price of food rises beyond the purchasing power of lower-income groups. It follows that famines are theoretically preventable via boosting wages through public works programs, or by severely restricting hoarding and speculation, both of which would ameliorate the widespread collapse of individual entitlement sets that necessarily precede famines (Sen, 1977; Ferguson, 2021).

The entitlement theory, primarily through attempting to serve as a strict alternative to the FAD hypothesis, has faced significant criticism and controversy. Many argue that it is far too broad an explanation, lacking both falsifiability and a sufficiently large set of tangible policy remedies, while other criticism has been levied on the grounds of insufficient scope (Devereux, 2001; Ó Gráda, 2009). Furthermore, the standard entitlement failure scenario, whereby a natural disaster severely reduces the quantity of fertile land and subsequently the demand for agricultural labor, depressing wages, departs from what is expected to occur under a nuclear winter. Whereas Sen's famines of study featured locally diminished harvests within countries that enjoyed yields sufficient for subsistence, such that starvation was primarily a function of maldistribution rather than scarcity, a nuclear winter would suppress yields across the entire growing hemisphere simultaneously, reducing yields under conventional production methods that no distribution of existing supply, however efficient and equitable, could fully remedy. There also exist several ways in which the value of, and therefore compensation for, human labor would both rise and fall under a nuclear winter scenario (rather than just fall under Sen's standard natural disaster $\rightarrow$ entitlement failure scenario) On the one hand, mortality deriving from the initial blast effect would reduce the labor supply, while the loss of agricultural infrastructure would yield a resurgence in both the need and subsequently the demand for animate labor power (Pamuk, 2007; Monteiro et al., 2026). Meanwhile, the mass displacement of urban populations into rural areas that is likely to occur under a nuclear winter scenario yields a flooding of the agricultural labor market with low-skilled workers (Sastry, Romm & Tsipis, 1987). Furthermore, the lack of complementary technology necessary for the massive increases in agricultural productivity over the 20th century suggests that the overwhelming majority of these roles consist of highly substitutable agricultural labor, further depressing wages (Ravallion, 1996).

However, would whatever wage earned by these unskilled workers be sufficient to mitigate short-term starvation? Feeding one person for a year, assuming they are strictly rationing their food, costs $\sim$ \$1800 (Denkenberger & Pearce, 2014). Hence, in the U.S., assuming that yearly income from such work is in the range of the country's current 10th percentile of $\sim$ \$11,000, working for subsistence could technically persist under an increase in food prices by a factor of ~ 6, suggesting that the poorer set of Americans would be priced out of subsistence only under a particularly extreme nuclear winter scenario (U.S. Census Bureau, 2025).

Furthermore, the price mechanism's response to food scarcity greatly alleviates the social burden arising from the market's absorption of a supply shock. In the short run, both demand and supply are more elastic than the acute price spike suggests. Regarding demand, consumers would tend to substitute away from staples and reduce waste via rationing. Meanwhile, regarding supply, producers redirect existing output away from less essential uses. Corn currently within the feed versus fuel cycle would very likely be diverted away from ethanol production and animal feed back toward direct human consumption at a quantity sufficient to feed the U.S. population for more than one year (Denkenberger & Pearce, 2014). Additionally, wherever possible, cultivation would shift towards the lower-input methods discussed in the previous section. Crucially, such re-allocations do not require any new storage capacity and can be acted upon quickly; provided that transaction costs remain low, spatial arbitrage manages to successfully move grain from surplus to deficit regions until the opportunity for further arbitrage is exhausted by the gradual convergence of regional prices (Jensen, 2007; Donaldson, 2018).

Furthermore, the same price increase would operate over the longer run as an intertemporal signal. A sustained elevation in food prices also indicates the prospect of future profits. This is the forward-looking component of the signal that would matter most for the alternative production methods discussed above. The natural recipients of that signal are both existing and prospective firms, including repurposing incumbents such as existing pulp and paper mills and breweries in addition to potential alternative food startups, that would be best positioned to convert any remnants of domestic industrial capacity towards producing food without relying on conventional agriculture. An equilibrium framework such as that of Hinge et al. (2026) exemplifies this logical sequence: prices remain elevated only so long as entry remains profitable, while margins gradually tend towards zero as capacity scales. We expect entrepreneurial entry en masse to respond to a price signal of this magnitude, as it has in less extreme episodes of scarcity.

In short, the market tends to self-correct. Where the price mechanism and its financing channels continue to function, producers expand output until prices fall back toward the level at which further entry is no longer profitable. However, when either the price mechanism or these channels are impaired, either the scarcity is not adequately communicated, or production capacity cannot expand to address it.

1.3: The Relationship between Prices, Institutions, and Development

A note on our epistemic posture before proceeding with this subsection is in order. The extensive debate over whether institutions cause economic prosperity or are merely correlated with it is not one this paper will either presume or attempt to settle. Hence, we do not claim that the institutions discussed below are necessary for growth. Rather, we argue that the price mechanism, as it operates today, functions most effectively through certain institutional arrangements that, at the very least, help to reinforce and facilitate impersonal exchange at scale. This is not to say that all forms of exchange would cease along with them, which could not be further from the expected outcome. The propensity to exchange emerges under virtually all scenarios involving humans living within geographic proximity of one another. Indeed, as an example relevant to this paper, such behavior crucially re-emerges in the wake of natural disasters to aid recovery (Storr, Haeffele-Balch & Grube, 2015; Wilson, 2025). However, for most of human history, exchange was embedded within social relations and therefore governed by reciprocity, kinship, and status, rather than by the price mechanism. Karl Polanyi, writing in The Great Transformation, argued that the image of a primordial bartering man is a "misreading of the past," positing instead that economies of the deep past were embedded within social relationships, with individuals acting to safeguard social standing instead of their material interest (Polanyi, 1944). While markets existed since the late Stone Age, they played a role largely incidental to economic life before the Industrial Revolution, with the sum-total of historical and ethnographical research "know[ing] of no economy prior to our own, even approximately controlled and regulated by markets" (Polanyi, 1944).[1] Hence, the self-regulating market, coordinated by an impersonal price mechanism, is an emergent and historically anomalous phenomenon arising through a deliberate institutional endeavor under which markets were "disembedded" from social relations such that society came to be organized around the market rather than the reverse. It naturally follows to consider how much, if any, of this inversion would survive the loss of the institutions that rendered it possible. Indeed, this inversion ultimately suggests that the modern market's capacity to both adequately distribute food and drive a necessary increase in production is predicated on the survival of the price mechanism that appears to be deeply intertwined with a small set of political and economic institutions.

Additional anthropological research into the rarity of price-coordinated markets has likewise demonstrated that barter is far less common than typically perceived. David Graeber's history of borrowing and lending in Debt finds that no society has relied on barter at scale (Graeber, 2011). In fact, credit systems even preceded coinage as the primary mechanism of exchange at scale, with history alternating between "ages of credit" and "ages of bullion" depending on the level of institutional trust within a society since the former's inception (Graeber, 2011). However, this historical priority of credit over coinage challenges a naive identification of money with physical currency and not the role of monetary institutions. The credit systems that preceded coinage were themselves denominated in administered standards of value. Indeed, Mesopotamian temple and palace debts, the first known instance of the use of credit within history, were written in shekels of silver with officially maintained barley equivalences. Hence, the historical record suggests that credit at scale requires a stable unit of account in which the future value of claims can be recorded and credibly priced. Hence, our concern with maintaining a "stable currency" discussed below should be interpreted as one with the stability of the monetary standard, of which coinage, paper, and electronic settlement largely serve as interchangeable vehicles.

Furthermore, barter has itself proven to emerge only contingently rather than serve as the foundational mechanism of exchange. Caroline Humphrey's "Barter and Economic Disintegration" (1985) alludes to the challenges of barter by showing that it has overwhelmingly been deployed across social boundaries and between groups rather than within them, and that it typically emerges in the

[1] By "our own," Polanyi means the system of self-regulating, price-coordinated markets that emerged with industrialization in nineteenth-century England. Polanyi (1944), ch. 4 ("Societies and Economic Systems"). [46]

wake of a monetary or credit breakdown rather than preceding one (Humphrey, 1985). Barter acting as a symptom of market disintegration rather than a naturally preceding stage further alludes to the existence of institutional prerequisites underlying a well-functioning market economy. It is also an inadequate replacement. Absent a general-purpose medium of exchange, every transaction requires a double coincidence of wants, which imposes sufficiently high search and negotiation costs to ensure that the majority of potential trades simply never materialize (Humphrey, 1985). Intra-societal exchange re-personalizes, with the majority of trading volume sharply contracting to those whom one trusts. Hence, the important question is not whether exchange will survive under a nuclear winter scenario. It absolutely will. Rather, we ask whether the institutional conditions for impersonal exchange at scale, coordinated via the price mechanism, do. If they do not, the literature predicts an explosion in transaction costs and exchange volume contraction that would strand food in surplus regions while deficit regions starve at virtually any nominal price (Humphrey, 1985).

Nowhere is this institutional dependence more acute than in credit and lending, upon which the supply response we discuss in 1.2 relies. Re-purposing and constructing alternative-food production capacity, or any production capacity for that matter, is a capital-intensive undertaking, plausibly on the order of hundreds of billions of dollars, if not more, over a twelve-month window (Denkenberger et al., 2022). Few, if any, responding firms could self-finance at that scale or speed. Hence, the expansion in production capacity depends on an intertemporal transaction whereby lenders and investors surrender resources today against claims on repayment months or years in the future. The existence of such a lending system at scale requires the repayment claim to be enforceable by a neutral third-party (contract institution), the unit in which it is denominated to be expected to hold value (monetary institutions), and the lender's gains to not be expropriable (property institutions) (North, 1991; Greif, 2006; Acemoglu, Johnson & Robinson, 2005). Payment and settlement systems, as Maurer (2012) emphasizes, are also not neutral plumbing beneath finance but relevant institutions in their own right. When any segment weakens, credit has consistently been shown to not only become less efficient but also contract in volume via personalization. Such a process may very well continue until only the strictly relational core remains, whereby credit is only extended to known partners within geographic proximity. Though this form of exchange predates and is therefore likely to outlive monetary institutions, it could not possibly facilitate a pulp-mill retrofit supply chain at any substantive capacity in twelve months. The financing terms are also crucial. Risk premia and real interest rates elevated by institutional uncertainty to a level rendering a twelve-month payback horizon unviable would impose a severe bottleneck on the expansion of trade and investment volume.

It is tempting to attribute this dependence to the technology of modern finance rather than to institutions, especially given the strong correlation between complexity of financial instruments and per capita GDP growth (King & Levine, 1993; Levine, 2005). However, this correlation is very likely confounded. Economic growth has often coupled the technology of modern finance together with the institutions beneath it, and the two co-vary positively (Olaniyi & Odhiambo, 2023). Meanwhile, the historical record offers a reasonably decisive test: lending at scale occurred millennia before nearly all of the relevant technology existed (Graeber, 2011), whereas credit contracts sharply when institutions fail even with the technology fully intact. This is not to dismiss the role of the techno-infrastructural layer within economic development; landmark studies by Donaldson (2018) and Jensen (2007) on India's railway network and mobile telephone coverage along the Kerala coast, respectively, document substantial gains in price information and market efficiency from the transportation and communication networks that suffer severe damage under certain nuclear winter scenarios. Furthermore, an electromagnetic pulse (EMP) that collapsed the electricity network would, among other things, reduce the dispersal of information, severely limiting both the knowledge of competitive prices and the reach of reputation on which informal ordering depends (Foster et al., 2008). However, while such losses remain recoverable and substitutable, so long as the institutions survive, the converse does not hold (Brown, 1968).

How confident should we be in the empirical evidence that institutions carry this weight? The clearest evidence in the neoinstitutionalist canon derives from research designs (i.e. natural experiments and within-country quasi-experiments in which culture, geography, and levels of human capital attainment are largely held fixed) rather than from cross-country correlations. Building on Acemoglu, Johnson & Robinson's (2005) landmark theoretical framework treating economic institutions as the fundamental cause of differences in international development, Ogilvie and Carus's (2014) survey of the vast historical evidence found that public-order institutions are necessary for markets to function, with even celebrated cases of "spontaneous" private merchant activity relying on the existence of either public courts or princely protection underneath. We do not claim that this research conclusively settles the deeper causal question regarding the co-evolution of and deeply complex relationship between culture and institutions, both of which very likely play at least some role in determining whether nations grow or remain in poverty (Alesina & Giuliano, 2015). Prosperity almost certainly does not have monocausal origins, and a plethora of neoinstitutionalist development economics research already addresses this exact question. However, this paper instead focuses on considering how the institutions of a comparatively prosperous country might fail under exogenous strain, with the evidence instead focusing on within-country collapse scenarios observed over timescales too short for culture or ethics to have changed significantly.

Hence, the possession of good institutions is not to be mistaken for their permanence. Recent history contains several cases of countries that grew under stable institutional arrangements before losing them as a result of exogenous shocks and subsequently stagnating. By 1929, Argentina's export-led growth model enjoyed nearly seven decades of stable constitutional government. However, the collapse in global foodstuff demand resulting from the Great Depression led to an economic contraction and subsequent military coup that ended the nation's constitutional rule and inaugurated a recurring cycle of political instability featuring six coups over the following half-century (1930, 1943, 1955, 1962, 1966, 1976) and no elected government completing a full transfer of power to an elected successor over that same period (Díaz Alejandro, 1970; della Paolera & Taylor, 2003). The poor quality of governance that followed severely inhibited long-term economic recovery from the depression, whereby per capita income, ranked among the world's ten highest and composing $\sim$ 70% of that of the U.S. in 1913, gradually fell to under a third of the U.S. level by 2000. More recently, Lebanon, which long served as a regional banking hub within the Middle East, faced geopolitical destabilization and refugee spillover resulting from the Syrian civil war throughout the 2010s, while mounting fiscal pressures challenged its sectarian power-sharing arrangement. This institutional paralysis culminated in the breakdown of both state solvency and the banking system in 2019 (World Bank, 2021). The resulting contraction in lending at scale and currency collapse bore significant economic effects, as per capita GDP plunged from an upper-middle-income level of roughly \$8,906 in 2019 down to a low of about \$3,478 by 2023, before slightly rebounding to \$4,473 in 2024 as the economy adapted to a heavily dollarized cash system (World Bank, 2021). Both of these cases demonstrate two relevant facts. First, institutional soundness is a state variable and not a trait, meaning that a sufficiently severe exogenous shock (i.e. a nuclear winter scenario) can undermine institutions that had been otherwise well-functioning for decades. Second, the damage persists far beyond the shock's duration. Even after conditions "normalized", neither country reverted to its pre-collapse trajectory, alluding to the existence of an asymmetry between failure and recovery that we will formalize below as hysteresis. Crucially, these facts seriously challenge the nuclear-recovery literature's historical tendency to assume the continuity of political authority and social order to isolate the economic problem (Brown, 1968).

These considerations narrow our attention to two institutions in particular, namely a stable currency and viable contract enforcement, with the relative degree of government legitimacy being treated as a standalone failure node. The case for the currency follows directly from the credit argument above: lending at scale requires a unit of account whose future value lenders can price in. Furthermore, when the unit destabilizes under hyperinflation, it is long-term-impersonal credit that dies first, well before day-to-day transactions shift away from using the currency. The case of Argentina in recent history is again useful here, though as a counterexample to be addressed. The country has faced decades of chronic inflation, with commercial activity having been conducted through indexation, rapid repricing, and parallel currencies. Meanwhile, the economy did not collapse into barter but instead has enjoyed a high degree of economic prosperity, especially relative to the rest of the world over the course of history. If a stable currency were strictly necessary for a well-functioning price mechanism, then Argentina's economy should not function at all. However, spot exchange (i.e a currency market) is what allowed the country's economy to survive the chronic inflation. The country's credit and lending industry operating under the peso, the margin of interest for this paper, did not survive. Argentina's domestic private credit has consistently hovered near $\sim$ 10–15% of GDP, among the lowest of any middle-income economy. Its mortgage market is effectively nonexistent, and the overwhelming majority of long-term contracts within the country are dollarized or indexed (della Paolera & Taylor, 2003; World Bank, 2021). Hence, only the substitution of someone else's currency has been adequate for lending at scale under a credible unit of account. Unfortunately, a severe nuclear winter forecloses this route, as the shock is global and the candidate refuge currencies would likely belong to the belligerents. Furthermore, under the scenarios whereby the U.S. is involved in the altercation, the dollar's own safe-haven status is undermined, with no viable substitute likely to emerge at scale.

The case for viable enforcement complements this need for a stable unit of account. We acknowledge that peacetime compliance is largely horizontal. That is, most contracts are performed not through court edict but instead through relational pressure and reputation concerns, with formal enforcement serving as the credibility backstop that makes dealing with strangers rational in the first place (Macaulay, 1963; Tyler, 1990; Ellickson, 1991). However, this backstop is what carries impersonal exchange beyond the reach of reputation, and a nuclear winter scenario could very well undermine several of these key horizontal channels. If both informal and formal enforcement fail under such conditions, whereby there is no neutral third party credibly capable of ensuring that contracts are honored, property rights and contracts, precisely the nodes that the institutionalist literature identifies as the precondition for investment and impersonal trade at scale, are enforced with much lower probability (North, 1991; Greif, 2006; Acemoglu, Johnson & Robinson, 2005; Ogilvie & Carus, 2014).

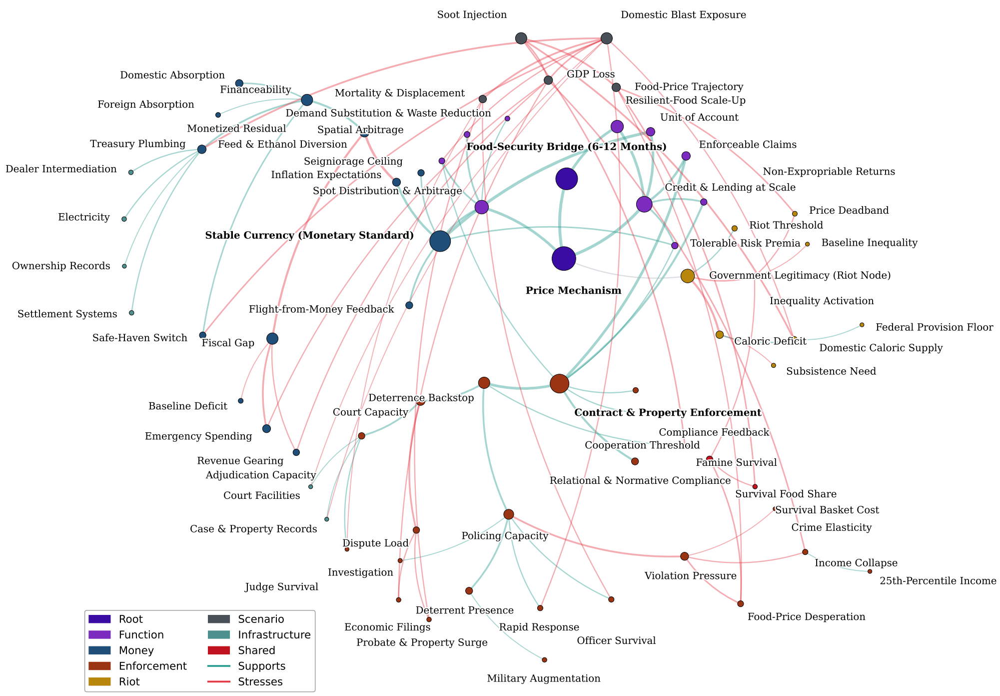

Figure 1: The institutional mapping of the model, as represented by a weighted, directed network, separated into colored groupings based on the institution that each specific node directly supports and Gephi's Fruchterman-Reingold layout. Thicker edges correspond to a more critical relationship between the specific function and its corresponding institution. The food-security bridge rests on the price mechanism, whose two functions, adequate geographic distribution and credit at scale, run through the two institutions of Section 1.3 (stable monetary standard, blue; contract and property enforcement, orange), and are shadowed by the legitimacy/riot node (gold). Each institution decomposes into the operational subcomponents of its damage function (to be explored in Section 2.5), and node size indicates structural weight and edge width a component's relative contribution, with green edges supporting and red edges stressing their targets. The scenario drivers (soot injection, blast exposure, and the derived GDP, price, and mortality trajectories) fan into all three families.

Section 2 - The Model

2.1 Motivation

In Section 1, we argued that whether or not critical food supplies actually reach people during the $\sim$ 6–12 month bridge before and during the scaling of resilient-food production would depend on the sustained functioning of the price mechanism. We in turn sought to demonstrate that the price mechanism appears to run through a small set of political and economic institutions. This section attempts to extend these qualitative claims into a quantitative consideration of the proximity between those institutions and failure under a set of nuclear winter scenarios. Any model that legitimately aids this consideration should reproduce three stylized facts suggested by the historical record of institutional collapse. First, institutional failure tends to be a gradual, and then sudden process (Ferguson, 2021).[2] Two key examples include Russia's monetary system, which did not in fact decline linearly with the breakdown of the USSR, and Lebanon's banking system in light of the 2019 crisis mentioned previously, which remained solvent up until several weeks before it completely collapsed. Second, failure and recovery are not mirror images of each other. It is worth noting that the historical record points to no major hyperinflation that ended through a gradual reversal of the conditions that produced it. Rather, each ended abruptly, upon a discrete and credible monetary regime change (Sargent, 1982). Hence, the model should be asymmetric, featuring a quantifiable difference between the respective paths down and back up. Third, the model must produce commensurable outputs (i.e. given in a common unit), allowing us to offer a rank of peacetime investments in light of a distance-to-failure value for both institutions within each scenario, comparable across institutions and scenarios. The coordination model we develop below corresponds to a straightforward formal structure that exhibits all three properties, with each following from a behavioral assumption rather than being imposed.

This assumption follows from our treatment of institutions not as formal pieces of parchment but rather as self-enforcing behavioral patterns. Specifically, we treat them as an equilibrium under which each agent's participation is rational through others participating, sustained principally by trust in its continued functioning (Schelling, 1960; Ostrom, 1990; Greif, 2006). Hence, money is not treated as the notes in circulation but rather the practice of enforcing them, while enforcement is not the legal code but rather the practice of honoring agreements in the expectation that shirking on one bears consequences. That is, an institution exists precisely to the extent that people behave as though it does, implying that "institutional health," an otherwise nebulous quantity, becomes observable as a participation share. Hence, we track two key shares:

- Currency as a Viable Nationwide Medium of Exchange: we denote the share $x_m \in [0, 1]$ as the fraction of transactions cleared in the national unit of account as opposed to either barter or foreign currency.
- Contract & Property Rights Enforcement: we denote the share $x_e \in [0, 1]$ as the fraction of economic obligations, namely contractual performance and respect for others' property, that agents honor rather than shirk in light of the enforcement guarantee provided by a governing authority.

We treat a stable institution as one whose participation share corresponds strictly

[2]This phrasing adapts the exchange in Hemingway's *The Sun Also Rises* (1926, Scribner): "How did you go bankrupt?" "Two ways. Gradually and then suddenly." Ferguson (2021) applies a similar trajectory to political and financial catastrophe.

to a positive margin between its fundamentals and the tipping threshold derived below. Hence, an institution's stability is a state variable directly influenced by the shock rather than some fixed trait. Furthermore, each participation share is governed by the same strategic logic. Namely, the private benefit to participation (i.e. compliance) is strictly increasing with the participation of others. Hence, a dollar is worth accepting and holding today only because tomorrow's counterparties are expected to accept it in turn. Meanwhile, contracts are worth honoring only when a sufficient proportion of existing contracts are honored such that the need for detecting shirking and enforcing punishments on it falls within the state's capacity, which keeps the guarantee of such enforcement credible in the first place. These strategic complementarities not only distinguish institutions from ordinary pieces of infrastructure but also explain the phenomena whereby they tend towards near-universal participation or near-universal abandonment as configurations that are individually rational for everyone simultaneously.

Furthermore, complementarity serves as the key assumption from which the three required facts discussed above follow. It renders each institution bistable, featuring functioning and collapse equilibria, separated by an unstable threshold. Hence, the scenario enters the model not by destroying the institutions directly but rather by depressing their fundamentals, denoted θ_i. That is, the monetization of an unfinanceable fiscal gap via printing money erodes the expected future value of the unit of account, the destruction of policing and court capacity erodes the expected consequences of violating the law, while a collapsing food supply and incomes provide further incentive to do so. So long as the fundamentals remain above the tipping threshold, the functioning equilibrium degrades only gradually, and the institutions hold even under severe stress. However, once either of the values crosses, the functioning equilibrium ceases to exist, and participation share suddenly falls discontinuously to the collapse equilibrium. Lastly, as abandonment shares high participation's self-reinforcing nature, merely restoring fundamentals to their tipping level is insufficient for restoring the institution itself. Indeed, the collapse equilibrium persists until fundamentals are raised to a strictly higher restoration threshold (mathematical explanation given in **Tipping, Hysteresis, Section 2.2**, proof given in Appendix A), with the gap between the two corresponding to the model's hysteresis, offering formal evidence for the claim that rebuilding is strictly more expensive than maintaining adequate prevention policies.

Modeling Each Scenario

We represent each nuclear winter scenario as a two-dimensional control variable,

$$s = (Q_{\text{soot}},\, E_{\text{infra}})\,,$$

where Q_{soot} denotes the global soot injection into the stratosphere and E_{infra} the domestic blast exposure of U.S. infrastructure (i.e. the expected percentage dropoff in productive capacity relative to peacetime levels, $E_{\text{infra}} \approx 0$ in the regional India–Pakistan scenario, where the U.S. is a bystander). These two variables operate as the two primary channels for which scenario-level estimates exist in the literature (Xia et al., 2022; Toon et al., 2019). Though the compression discards a significant quantity of information, most notably targeting geography, fallout, and strike timing (with the influence of lower temperatures and a disrupted hydrological cycle effectively being accounted for by Q_{soot} in light of our mapping expected decreases in caloric production primarily from existing literature), with effects we cannot recover (we return to this limitation in Section 3.3), they serve as the primary components of the expected institutional damages in the wake of a nuclear winter to be developed in Section 2.5.

The primary channel through which s reaches the institutions is through the induced yield dropoff. Drawing on the crop-model estimates of Xia et al. (2022), we map each soot level to an expected reduction in U.S. domestic caloric production corresponding to $\sim$ 10% at 5 Tg and $\sim$ 20% at 13 Tg, $\sim$ 50% at 47 Tg, $\sim$ 85% at 80 Tg, and $\sim$ 95% at 115 Tg. While the lower three shocks are severe enough to sharply increase prices while leaving production well above domestic subsistence, under the upper two levels U.S. domestic production alone approaches and begins to fall below the surviving population's caloric requirement (Xia et al., 2022; Hinge et al., 2026).[3]

These production losses naturally drive the food-price trajectory $\pi(s)$, a fair portion of the GDP contraction $g(s)$, and the caloric supply term entering the legitimacy node, thereby propagating into every damage function of Section 2.5. However, the two scenarios diverge in more than just soot quantity. Specifically, the same 47 Tg injection costs the United States approximately twenty additional percentage points of production when it appears as the great-power first case rather than the India–Pakistan terminal case, with such a difference resulting entirely from E_{infra}, the direct destruction of domestic agricultural and industrial capacity. It is this infrastructural gap, alongside the loss of the dollar's safe-haven status, where the qualitative difference between being a bystander and a belligerent enters the model. Furthermore, as Section 3 will demonstrate, these belligerent-specific channels ultimately account for the majority of the difference in institutional outcomes between the two scenarios.

A brief note on units is also in order. The fundamentals θ_i are measured in logistic units (logits): a one-unit movement in θ_i corresponds to a one-unit shift in the natural logarithm of the event's odds (with probability p, this corresponds to $\ln\left(\frac{p}{1-p}\right)$) that a representative agent participates, holding others' behavior fixed. Each institution's failure margin (distance between its post-shock fundamental and tipping threshold) is denominated in these same units, as are the damage functions. This gives the model's outputs a precise relative meaning, as we can discern which institution sits closest to its cliff, under which scenarios it crosses, in what order failures would arrive, and how large, relative to the original margin, the required restoration effort would be. However, a logit is of course not a dollar, and we make no claim to translate these margins into precise dollar quantities of

[3]These figures capture the climatic (soot) channel alone; the additional production losses from direct damage to agricultural and industrial infrastructure under the great-power scenario enter separately through E_{infra}, as discussed in the following paragraph.

either damages or optimal peacetime investment. We can only be certain that the former is strictly greater than the latter.

2.2 Intra-institutional Dynamics

We let $x_i \in [0,1]$ be an institution's participation share and $\theta_i \in [0,1]$ be its level of structural soundness. This is a quasi-unobservable parameter that we derive from x_i. Agents adopt a smooth best response to the aggregate share, which yields the mean-field fixed-point equation

$$x_i \;=\; F(\theta_i + \lambda_i x_i)\,, \qquad F(z) = \sigma\left(\tfrac{z}{\epsilon}\right) = \frac{1}{1+e^{-z/\epsilon}},$$

where $\lambda_i > 0$ is strategic-complementarity strength (how sharply the incentive to participate rises with others' participation) and ϵ is response heterogeneity. F, the Cumulative Distribution Function (CDF) of the logistic distribution (resembling the bell-shaped curve but with larger tails than the normal distribution), computes the probability that a given agent finds continued participation optimal, which is equivalent to the fraction of the population whose threshold falls below the net incentive $\theta_i + \lambda_i x_i$. Naturally, this proportion will increase with a fundamentally sound institution (higher θ_i), with higher levels of current participation (higher x_i), and with a stronger complementary incentive (higher λ_i). Furthermore, this participation probability must naturally equate to the aggregate share x_i such that an equilibrium emerges at the fixed point $x_i = F(\theta_i + \lambda_i x_i)$.

Equilibria and Stability. We let $G(x_i, \theta_i) = F(\theta_i + \lambda_i x_i) - x_i$ such that fixed points solve $G = 0$. Furthermore, such a fixed point is stable if and only if small changes in the population share x_i push the system back to the fixed point:

$$\frac{\partial G}{\partial x_i} = \lambda_i F'(\theta_i + \lambda_i x_i) - 1 < 0.$$

Bistability Threshold: To find where the system changes behavior completely, we consider the tipping point under which the fixed point loses its stability. Namely, the saddle-node tangency where the derivative equates to zero:

$$\frac{\partial G}{\partial x_i} = 0,$$

which is equivalent to

$$\lambda_i F'(\theta_i + \lambda_i x_i) = 1$$

By definition of the logistic probability distribution, we know that F has maximal slope of $1/4\epsilon$ (derivation given in Appendix A), and to achieve a tangency, we need this maximum slope to exceed that corresponding to the fixed point featuring the loss of stability:

$$F'_{\text{max}} > 1/\lambda_i,$$

meaning that the institution is bistable (i.e. capable of tipping at all) if and only if

$$\frac{1}{4\epsilon} > \frac{1}{\lambda_i} \iff 4\epsilon < \lambda_i.$$

Below this ratio, $G = 0$ has a single fixed point and the institution degrades smoothly; above it there are two stable fixed points, one closer to 1 corresponding to the institution holding, and another near 0 corresponding to effective collapse, and an unstable one in between them.

Tipping, Hysteresis. As θ_i falls, the higher stable fixed point and the unstable middle point collide and annihilate at a saddle-node bifurcation, which we denote as θ_i^{tip}.

Below it, collapse becomes the unique outcome such that the participation share jumps downward discontinuously. It is worth noting that recovery is not simply the downward path in reverse. Rather, the collapse root persists until a strictly higher threshold $\theta_i^{\text{restore}} > \theta_i^{\text{tip}}$ is reached, such that re-establishing the "better" equilibrium requires a discrete, credible regime change shifting the actual saddle path. The closed forms are given as:

$$\theta_i^{\text{tip}} = \epsilon \ln \frac{x_{i+}}{1 - x_{i+}} - \lambda_i x_{i+}, \qquad \theta_i^{\text{restore}} = \epsilon \ln \frac{x_{i-}}{1 - x_{i-}} - \lambda_i x_{i-}, \qquad x_{i\pm} = \frac{1 \pm \sqrt{1 - 4\epsilon/\lambda_i}}{2},$$

while hysteresis width is given by $\theta_i^{\text{restore}} - \theta_i^{\text{tip}} = \lambda_i \, h(a) > 0$ with $a = \sqrt{1 - 4\epsilon/\lambda_i}$ and $h(a) = a - (1 - a^2)\,\text{arctanh}(a)$ (derivation and sign proof given in Appendix A). This is a formalization of fact that restoration and collapse are not mere opposites of one another. Graphically, this appears as

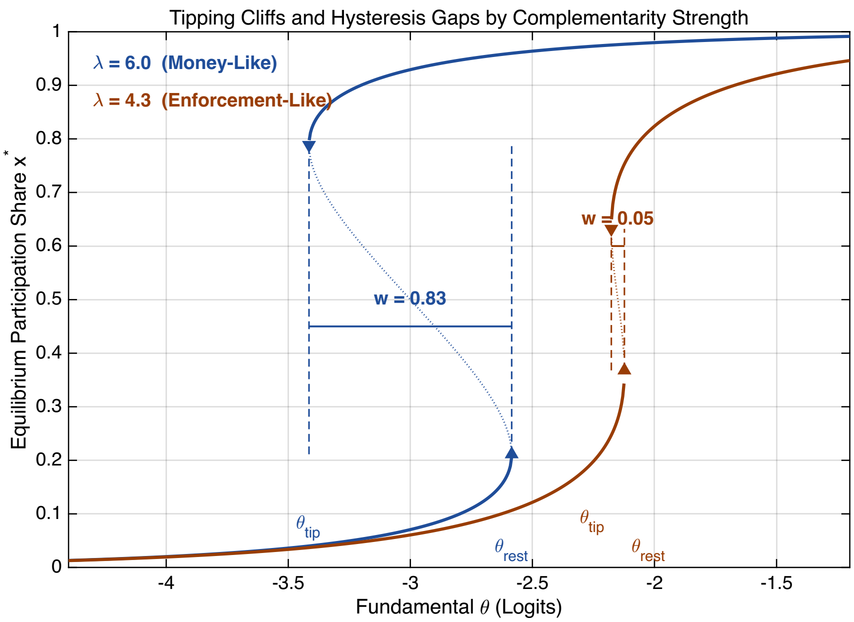

Figure 2: Equilibrium participation share x^* as a function of the institutional fundamental θ under money-like ($\lambda = 6$) and enforcement-like ($\lambda = 4.3$) complementarity. Solid segments are stable branches, dotted segments unstable, with triangles marking the saddle-nodes. Money's stronger complementarity yields a steeper cliff and a wide hysteresis gap ($w \approx 0.83$); weaker complementarity a shallower fold and a nearly closed gap ($w \approx 0.05$). The discontinuity emerges from our treatment of θ^{tip} and θ^{restore} as quantitatively different closed forms (seen above).

Normalization of ϵ : The map depends on $(\theta_i, \lambda_i, \epsilon)$ only through the ratios θ_i/ϵ and λ_i/ϵ, which in turn implies that a redundant degree of freedom exists. We subsequently fix $\epsilon = 1$ throughout and proceed by measuring θ_i and λ_i in logistic units (logits), while the bistability threshold reads $\lambda_i > 4$. Only the ratio λ_i/ϵ is empirically identified from tipping behavior.

2.3 The Fragility Index

As θ^{tip} is derived from (λ, ϵ) , each institution's fragility is the signed distance of its effective (after accounting for post-detonation damages) fundamental from its cliff, $m_i = \theta_i^{\text{eff}} - \theta_i^{\text{tip}}$. We let the country-level index correspond to the negative of the weakest institution's margin:

$$\Phi_{\text{inst}}(s) \;=\; -\min_{i \in \{m,e\}} \left(\theta_i^{\text{eff}}(s) - \theta_i^{\text{tip}} \right) .$$

Our use of min derives from emphasis on whichever the weakest critical institution may be, as we would expect cascading effects of just one institutional failure via interdependence. It is worth emphasizing that this expectation of cascading failure is an assumption rather than a derived result. Meanwhile, the leading minus converts a robustness measure into a fragility measure. Φ_{inst} crosses zero exactly at the collapse boundary such that $\Phi > 0$ if and only if at least one institution has tipped, and its magnitude corresponds to the severity of the breach. Hence, any policy measure is effective precisely to the extent it lowers Φ_{inst}.

2.4 Cross-Institutional Structure

We proceed by solving two uncoupled fixed-point problems and a threshold condition:

$$x_m = F(\theta_m(s)+\lambda_m x_m), \qquad x_e = F(\theta_e(s)+\lambda_e x_e), \qquad \text{riot possible when } U(s) \geq U^*.$$

As discussed in Sections 2.1 and 2.5.3 (see below), we treat the grievance-based failure node $U(s)$ as an event threshold (specifically food-riots) rather than a sustained participation equilibrium, whereby our case-based calibration recovers a grievance threshold U^*, the implied grievance level at which historical governments fell. Coupling between this failure node and the other two institutions follows from our expectation that the monetary and law enforcement systems would collapse along with the government in the wake of a successful coup. The model also accounts for monetary and enforcement failure raising riot risk, primarily through the damage functions sharing price trajectory $\pi(s)$ and household income functions shared by all three primary functions. More decisively, we calibrated U^* from several historical collapse episodes in which the critical surrounding institutions were themselves already beginning to fail, suggesting that the estimated threshold already embeds a degree of concurrent institutional distress. The two institutional damage functions are coupled in a limited capacity for the same reason.

2.5 Damage Functions

The shock does not influence x_i directly. Instead, it lowers each institution's fundamental in proportion to the normalized severity of its driver (equating to 1 at the institution's critical magnitude), while we treat the food riot node as a threshold condition (See Section 2.4):

$$\theta_m(s) = \theta_m^0 - \phi_m \frac{D_{\text{fisc}}^{\text{mon}}(s)}{d^*}, \qquad \theta_e(s) = \theta_e^0 - \phi_e \frac{\delta_0 - \delta_{\text{eff}}(s)}{\delta_0 - \delta^*}, \qquad \text{sev}_g(s) = \frac{U(s)}{U^*},$$

with each severity function receiving further treatment in the subsections below. However, we must first offer a full verbal interpretation of the coefficients ϕ_m and ϕ_e. Each ϕ_i is determined by the equation

$$\phi_i = \theta_i^0 - \theta_i^{\text{tip}},$$

which corresponds to the baseline fragility margin for each institution such that each institution tips precisely when severity equates to one. As the margins themselves vary according to stance, we have that $\phi_m \approx 0.91$, 1.43, and 2.30 under the fragile, middle, and robust stances, respectively, and $\phi_e \approx 0.12$ and 0.29 under the fragile and middle stances, respectively. Under the robust stance, λ_e falls below the bistability threshold of 4 such that enforcement possesses no cliff and hence lacks a corresponding ϕ_e. ϕ_m is comparatively large in light of the dollar's larger baseline "cushion," which results from near-universal use of the dollar as the world's leading reserve currency during peacetime, while failure emerges from a fiscal gap being monetized up until the seigniorage[4] ceiling d^* eroding the entire cushion in a process consistent with the record on hyperinflation, whereby currency flight results from printing currency as the only result of financing government operations. Meanwhile, ϕ_e is comparatively small in light of peacetime enforcement viability resting much closer to the tipping point, while failure emerges from deterioration of effective deterrence (i.e. an adjusted discount factor) from δ_0 toward the cooperation-collapse threshold δ^* following a variety of factors.

2.5.1 Money: a Fiscal Driver D_{fisc} and Financeability $b(s)$

The fiscal gap is linearized in the fractional GDP loss $g(s) = \frac{Y_0 - Y(s)}{Y_0}$, where Y_0 is baseline GDP and $Y(s)$ is GDP after the given shock. Hence, we have that

$$D_{\text{fisc}}(s) = \frac{\text{emergency expenditure}(s) + [\text{revenue}_0 - \text{revenue}(s)]}{Y(s)},$$

and linearization approximately yields

$$d_0 + \kappa_{\text{rev}}\, g(s) + e_{\text{emg}}(s),$$

with d_0 being the baseline structural deficit, κ_{rev} being the automatic revenue-loss parameter, and e_{emg} discretionary emergency expenditure, expressed as a function of shock magnitude. Furthermore, only the part that must be monetized (i.e. the deficit that cannot be financed by borrowing) threatens the currency's stability:

$$\text{severity}_m(s) = \frac{D_{\text{fisc}}^{\text{mon}}(s)}{d^*} = \frac{\max(0,\ D_{\text{fisc}}(s) - b(s))}{d^*},$$

with

$$b(s) = f_{\text{plumb}}(s) \cdot [b_{\text{dom}} + b_{\text{for}}\, I_{\text{reserve}}].$$

Hence, $b(s)$ is the U.S. bond market's absorption capacity, a function of both capacity and demand. f_{plumb} acts as the operational capacity of the Treasury-market's technical infrastructure in light of a blast (specifically considering the E_{infra} factor) , b_{dom} and b_{for} correspond to domestic and foreign absorption of U.S. debt, and $I_{\text{reserve}} \in [0, 1]$ acts as a binary safe-haven switch (i.e. whether or not the U.S. dollar is believed to remain a viable store of value). For the US, monetary

[4] Seigniorage is effectively the real revenue a government obtains by issuing (i.e. printing) new base money.

fragility lives entirely in $b(s)$. Though the deficit is financeable at baseline, the currency can tip in light of the destruction of financial infrastructure or the dollar's role as a safe-haven flips. The critical value d^* represents the empirical ceiling on a state's monetizable deficit before hyperinflation occurs, and is approximately 20% of GDP.

2.5.2 Enforcement

Contract and law enforcement is sustained if and only if the effective discount factor exceeds the threshold of $\delta^* = .5$ that acts as a minimum requirement for a functioning, cooperative society. A nuclear winter scenario reduces the baseline discounting factor of $\delta_0 = .99$ through two channels: intertemporal mortality (agents and counterparties may not survive into the next period) and the degradation of the viability of formal sanctions (misbehavior becoming less likely to be detected and adjudicated):

$$\delta_{\text{eff}}(s) = \delta_0 \cdot \underbrace{p_{\text{surv}}(s)}_{\text{survival of the altercation's second-order effects}} \cdot \underbrace{E(s)}_{\text{sanction credibility}},$$

where

$$E(s) = P(s)^{1/2}\, C(s)^{1/2},$$

and $p_{\text{surv}}(s)$ is derived from the famine-mortality projections offered by Xia et al. (2022) (first-order blast effect deaths enter the equation separately as $m(s)$), and $E(s)$ integrates the two arms of formal enforcement, namely, policing and adjudication, as complementary factors, each expressed as a capacity-utilization ratio normalized to one at the peacetime baseline:

$$P(s) = \min\left(1,\ \frac{\text{policing supply}(s)}{\text{violation pressure}(s)}\right), \qquad C(s) = \min\left(1,\ \frac{\text{adjudication capacity}(s)}{\text{dispute load}(s)}\right),$$

where

$$\text{policing supply}(s) = \underbrace{(1 - m_{\text{urban}}(s) - d_{\text{officer}}(s))}_{\text{officers alive and working}} \cdot \underbrace{o(s)}_{\text{surviving detection and enforcement technology}},$$

where

$$o(s) = \underbrace{0.5 \cdot [\varphi_f + (1-\varphi_f)\, f_{\text{mob}}] \cdot f_{\text{disp}}^{0.3} \cdot (1 + \text{mil}(s))}_{\text{deterrent presence}} + \underbrace{0.3 \cdot f_{\text{disp}} \cdot f_{\text{mob}}}_{\text{rapid response capacity}} + \underbrace{0.2 \cdot r_{\text{pol}} \cdot f_{\text{disp}}}_{\text{investigation capacity}}.$$

Here, $m_{\text{urban}}(s)$ is the urban (and therefore roughly equivalent to police force) mortality rate, while $d_{\text{officer}}(s)$ corresponds to the officer desertion rate such that 1 minus the sum of these two proportions corresponds to the remaining share of the nation's peacetime police force. Military-based enforcement is accounted for and will be considered below.

For actual enforcement capacity, $o(s)$, we place primary emphasis on the visible presence of a viable deterrent, which has shown to be strongest reducer of crime.

It is defined by the sum of the share of the population living at densities policeable on foot, φ_f, and the product of the share that is not and the surviving fraction of mobile response capacity, $f_{\text{mob}}(s)$. This value is then multiplied by the fraction of the coordination system that survives, $f_{\text{disp}}(s)$, raised to an exponent well below one to reflect that coordination depends weakly on central dispatch. That is, precincts have historically operated semi-autonomously before radio coordination existed, so uncoordinated presence degrades but does not vanish. Lastly, the factor $(1+\text{mil}(s))$ augments this presence channel, with deployed military power expressed equivalently to police presence, as soldiers under a domestic-order tasking (such as the national guard) substitute effectively for patrol visibility.

The second channel, rapid response capacity, accounts for the fact that a call must both be received (hence $f_{\text{disp}}(s)$) and physically reached ($f_{\text{mob}}(s)$), such that the two factors enter multiplicatively. Both the literature and empirical record find that response speed contributes far less to sanction credibility than intuition may suggest.

The third channel, investigation, requires both records access ($r_{\text{pol}}(s)$, namely, identification databases which are stored with redundancies but require certain infrastructures to recover) and communications, and receives the smallest weight in light of clearance-driven deterrence being shown to be comparatively weaker at the peacetime baseline.

Next, we have

$$\text{violation pressure}(s) = 1 + \varepsilon_{pc} \cdot \Big[\underbrace{e(s) \cdot \Delta \ln P_{\text{food}}(s)}_{\text{price channel}} \; + \; \underbrace{\ln\Big(\frac{y_0}{y(s)}\Big)}_{\text{income channel}} \Big],$$

with the food-budget share itself being endogenous to the scenario:

$$e(s) = \min\Big(e_{\max},\ \max\Big[e_{\text{base}},\ \frac{c_{\text{subsist}} \cdot \pi(s)}{y(s)}\Big]\Big), \qquad y(s) = y_0\big(1 - \gamma_y\, g(s)\big).$$

The food scarcity and subsequent price shock leads to predation in two steps. First, the rise in food prices, given by $\Delta \ln P_{\text{food}}$ costs a household approximately $e(s) \cdot \Delta \ln P_{\text{food}}$ of its real income (the first-order welfare loss of a price change is the price change weighted by the good's budget share, $e(s)$, which denotes the fraction of 25th percentile income spent on food). Meanwhile, the income channel captures the logarithmic decline in the poor household's income under the scenario's expected GDP contraction. Second, the elasticity coefficient ε_{pc} converts real-income loss into property crime, and is calibrated from the historical record and then discounted due to modern consumption-smoothing and subsidy measures that the historical poor lacked.

The logarithmic form keeps both channels in the units under which ε_{pc} is calibrated, renders the decomposition of real-income loss exact, and accounts for the appropriate convexity, whereby early income losses cut comforts while later ones cut subsistence, meaning that desperation escalates faster than linearly as income approaches zero. $e(s)$, the rise in bottom quartile budget allocated towards subsistence, is capped by the min operator at either e_{max}, the famine-economy income share ceiling (as even starving households must devote some portion of their income to shelter and fuel), or the tentative increase in the share of this household's budget allocated to food, relative to peacetime. This share is given by the product of c_{subsist}, the annual cost, at current prices, of the cheapest caloric survival basket, and $\pi(s)$, the staple-price multiple under scenario s, divided by $y(s)$, the post-shock income of this household. This last function equates to peacetime income y_0, reduced by the scenario's GDP contraction $g(s)$ (the same contraction variable that drives the fiscal deficit in the money damage function), scaled by a factor $\gamma_y > 1$ accounting for the tendency of low-income earnings to fall faster than aggregate output in downturn.

The change in adjudication capacity is given by:

$$\text{adjudication capacity}(s) = \underbrace{(1 - m_{\text{urban}}(s) - d_{\text{judge}}(s))}_{\text{judges alive and working}} \cdot \underbrace{(f_{\text{facility}}(s) \cdot r_{\text{records}}(s))^{\frac{1}{2}}}_{\text{court operability}}$$

We recycle $m_{\text{urban}}(s)$ from the policing side, as court personnel share the same urban concentration, while $d_{\text{judge}}(s)$ is the absence and displacement rate of judges, clerks, and prosecutors such that 1 minus these two values again yields the functional share of critical courtroom employees.

Meanwhile, we treat court operability as a serial pipeline, whereby every case must pass through a venue (f_{facility}) and accessible records (r_{records}, whose existence is rarely destroyed but whose retrieval again relies on certain pieces of infrastructure). Hence, the two factors compound multiplicatively but are softened by a square root that reflects the workarounds of relocation and analog processes.

Lastly, the expected increase in cases is given as

$$\text{dispute load}(s) = 1 + \underbrace{\ell_g \cdot g(s)}_{\text{economic disputes}} + \underbrace{\rho_{\text{file}} \cdot s_{pb} \cdot \left(\frac{m(s) + \text{disp}(s)}{m_{\text{norm}}} - 1\right)}_{\text{death and property disputes}},$$

where the first term captures the surge in defaults, insolvencies, and contract disputes that would accompany the expected economic contraction, with elasticity parameter ℓ_g measuring the standard increase in such disputes per every percent fall in GDP.

Meanwhile, the second term captures the flood of potential claims generated by mass death and displacement: s_{pb} is the share of the civil docket sensitive to death and severe property disruption, and dividing the crisis death and displacement share by normal annual mortality m_{norm} and displacement $\text{disp}_{\text{norm}}$ expresses the shock as years of ordinary probate demand arriving simultaneously. The filing-realization factor ρ_{file} discounts this latent volume to the fraction that actually reaches a clearly swamped forum.

Specific parameter intervals are given in Section 2.7. Full sub-functions and subsequent outputs, in addition to parameter justification, are given in Appendix B.5. Severity is then measured against the cooperation threshold, beyond which public enforcement is no longer viable:

$$\text{severity}_e(s) = \frac{\delta_0 - \delta_{\text{eff}}(s)}{\delta_0 - \delta^*} = \frac{.99 - \delta_{\text{eff}}(s)}{.49}.$$

2.5.3 Government Legitimacy and the Grievance Driver $U(s)$

We consider public grievance as a function of hunger and the underprovision of necessities more generally:

$$U(s) = \alpha_{\text{need}}\, N(s) + \alpha_{\text{fair}}\, \text{Gini}_0 \cdot \min\{e(s) \cdot (\pi(s) - 1),\, 1\}, \qquad \text{severity}_g(s) = \frac{U(s)}{U^*},$$

where

$$N(s) = \frac{\max\{0,\ \text{need}(s) - \text{supply}(s)\}}{\text{need}(s)}, \qquad \text{need}(s) = \text{pop}(s) \cdot 1800 \cdot 365,$$

with need(s) the aggregate subsistence requirement of the surviving population at 1,800 kcal per person per day, and supply(s) the expected yearly caloric output under the scenario (domestic production under the prevailing yield reduction, plus any released reserve or subsidized quantities). We therefore treat $N(s)$ as the fraction of subsistence need that the year's food balance cannot cover.

The fairness term treats inequality as a latent fragility that requires a price shock to activate: a population tolerates a given level of measured inequality at stable prices, but a spike in staple prices could convert this inequality towards deprivation as the poor are priced towards the subsistence threshold. Here Gini_0 is baseline U.S. income inequality, while $\pi(s)$ is the staple-price multiple under scenario s, and $e(s)$ is the endogenous food-budget share of the poor household defined above, which converts the price rise into the real-income loss it inflicts at the bottom of the distribution; the min operator caps the activation at one, beyond which further price increases do not contribute to distributional grievance. This specification helps account for high-inequality societies not necessarily tipping at stable prices and historically modest price increases sufficing to tip societies whose poor spent most of their income on food. Applied retrospectively to the historical collapse cases assembled in Appendix B.6a, the same two-term formula yields an implied grievance value (taken as an arithmetic mean of all cases) of $U \approx 0.083$ at the moment each government fell.

2.6 Solution Algorithm

We start at the pre-shock healthy equilibrium $\mathbf{x} \approx (1, 1, 1)$ and apply the scenario shift to $(\theta_m, \theta_e, \theta_g)$, and iterate damped best responses towards convergence:

$$x_i^{t+1} = (1 - r)\, x_i^t + r\, F\Big(\theta_i(s) + \lambda_i x_i^t\Big), \qquad r \in (0, 1].$$

The relaxation rate r is a solution parameter. That is, the time-step of the adjustment flow $\dot{x}_i = F(\cdot) - x_i$, that leaves the fixed points and basins invariant, and it only needs to be small enough such that the iteration contracts rather than oscillates.

Three scalars converge in milliseconds, so the whole procedure is wrapped in a sensitivity sweep over a range of values for the uncertain parameters $\theta_i^0, \lambda_i, \phi_i$.

2.7 Parameter Calibration

All intervals are given via $\sim$ 90% confidence and propagated throughout the analytical solution such that key results — margins, hysteresis widths, and Φ_{inst} — are themselves reported as ranges; the three parameter stances of Section 3 (fragile, middle, robust) correspond to the adverse bound, center, and favorable bound of each interval. Epistemic status is denoted as follows: **[D]** based entirely on empirical data, **[C]** data-bracketed, while the value is a constructed/normalized choice, **[E]** elicited prior (verbal justification given in Appendix B). It is worth noting that for parameters of this last kind, the relative ordering across institutions — where we are considerably more confident — is what drives the meaningful differences in output, rather than any parameter's point value. Also note that the normalization $\epsilon \equiv 1$ yields the expression of θ, λ, ϕ in logit units.

Baseline Proportions x_i^{*0} (θ_i^0 derived via $\theta_i^0 = \ln \frac{x_i^{*0}}{1-x_i^{*0}} - \lambda_i x_i^{*0}$; the riot node requires no baseline share):

Institution	center	90% CI	status
Money x_m^{*0}	0.98	[0.97, 0.99]	[C]
Enforcement x_e^{*0}	0.85	[0.80, 0.89]	[C]

Complementarity Parameters λ_i (the ordering $\lambda_m > \lambda_e$ being the more important and defensible factor):

	center	90% CI	status
λ_m	6.0	[5.0, 7.0]	[E]
λ_e	4.15	[3.75, 4.3]	[E]

Note that the favorable bound of λ_e falls below the bistability gate $\lambda = 4$: under the robust stance, enforcement possesses no cliff and degrades smoothly.

Money Damage-Function Parameters (the scenario-indexed inputs $e_{\text{emg}}(s)$, $f_{\text{plumb}}(s)$, $g(s)$, and $\pi(s)$ are tabulated separately below):

Parameter	center	90% CI	status
d^* (monetized-deficit ceiling, /GDP)	0.20	[0.15, 0.25]	[C]
d_0 (baseline deficit /GDP)	0.06	[0.05, 0.07]	[D]
κ_{rev} (revenue gearing)	0.275	[0.20, 0.35]	[D]
b_{dom} (domestic absorption /GDP)	0.175	[0.10, 0.25]	[C]
b_{for} (foreign absorption /GDP)	0.06	[0.02, 0.10]	[C]
I_{reserve} (safe-haven switch)	1 (S1) / 0 (S2)	—	[C]

Riot-Node Parameters:

Parameter	center	90% CI	status
$\alpha_{\text{need}}, \alpha_{\text{fair}}$	0.60, 0.40	—	[E]
Gini_0 (baseline U.S. income inequality)	0.418	—	[D]
U^* (case-calibrated riot threshold, §B.6a)	0.083	—	[D/C]

Section 3 - Results, Policy Prescriptions

3.1 Results

We evaluate the model across the six scenarios under three stances: a pessimistic case that takes the ends of every 90% parameter interval closer to the tipping threshold, an optimistic case at all of the opposite (and therefore robust) ends, and a median case at the approximate center of every interval. Considering these three fragile-robust cases at all three blast-mortality levels (for the U.S. - Great Power scenario) within the three soot-magnitude cases constituting the two scenarios yields 36 total cases.

S1C1 — India–Pakistan, 5 Tg:

blast death rate	stance	sev_m	sev_e	sev_g	riot	margin_m	margin_e	verdict	Φ	$\Delta\theta_m^{\text{rec}}$	$\Delta\theta_e^{\text{rec}}$
0%	frag.	0.00	0.26	0.00	n	+0.91	+0.09	none	−0.09	0.00	0.00
0%	mid.	0.00	0.08	0.00	n	+1.43	+0.27	none	−0.27	0.00	0.00
0%	rob.	0.00	0.01	0.00	n	+2.30	—	none	−2.30	0.00	0.00

blast death rate	stance	sev_m	sev_e	sev_g	riot	margin_m	margin_e	verdict	Φ	$\Delta\theta_m^{\text{rec}}$	$\Delta\theta_e^{\text{rec}}$

S1C2 — India–Pakistan, 13 Tg:

blast death rate	stance	sev_m	sev_e	sev_g	riot	margin_m	margin_e	verdict	Φ	$\Delta\theta_m^{\text{rec}}$	$\Delta\theta_e^{\text{rec}}$
0%	frag.	0.23	0.47	0.06	n	$+0.70$	$+0.06$	none	-0.06	0.00	0.00
0%	mid.	0.00	0.19	0.00	n	$+1.43$	$+0.24$	none	-0.24	0.00	0.00
0%	rob.	0.00	0.06	0.00	n	$+2.30$	—	none	-2.30	0.00	0.00

S1C3 — India–Pakistan, 47 Tg:

blast death rate	stance	sev_m	sev_e	sev_g	riot	margin_m	margin_e	verdict	Φ	$\Delta\theta_m^{\text{rec}}$	$\Delta\theta_e^{\text{rec}}$
0%	frag.	1.33	1.05	0.61	n	-0.30	-0.01	$\text{M} \to \text{E}$	$+0.30$	1.75	0.06
0%	mid.	0.00	0.52	0.61	n	$+1.43$	$+0.14$	none	-0.14	0.00	0.00
0%	rob.	0.00	0.18	0.61	n	$+2.30$	—	none	-2.30	0.00	0.00

S2C1 — U.S.–Great Power, 47 Tg:

blast death rate	stance	sev_m	sev_e	sev_g	riot	margin_m	margin_e	verdict	Φ	$\Delta\theta_m^{\text{rec}}$	$\Delta\theta_e^{\text{rec}}$
9%	frag.	3.07	1.82	0.87	n	-1.88	-0.10	$\text{M} \to \text{E}$	$+1.88$	3.33	0.15
	mid.	1.17	1.47	0.61	n	-0.24	-0.14	$\text{E} \to \text{M}$	$+0.24$	1.07	0.16
	rob.	0.00	0.97	0.61	n	$+2.30$	—	none	-2.30	0.00	0.00
12.5%	frag.	3.07	1.87	0.82	n	-1.88	-0.11	$\text{M} \to \text{E}$	$+1.88$	3.33	0.16
	mid.	1.17	1.58	0.61	n	-0.24	-0.17	$\text{E} \to \text{M}$	$+0.24$	1.07	0.19
	rob.	0.00	1.15	0.61	n	$+2.30$	—	none	-2.30	0.00	0.00
16%	frag.	3.07	1.91	0.75	n	-1.88	-0.11	$\text{M} \to \text{E}$	$+1.88$	3.33	0.17
	mid.	1.17	1.69	0.61	n	-0.24	-0.20	$\text{E} \to \text{M}$	$+0.24$	1.07	0.22
	rob.	0.00	1.35	0.61	n	$+2.30$	—	none	-2.30	0.00	0.00

S2C2 — U.S.–Great Power, 80 Tg:

blast death rate	stance	sev_m	sev_e	sev_g	riot	margin_m	margin_e	verdict	Φ	$\Delta\theta_m^{\text{rec}}$	$\Delta\theta_e^{\text{rec}}$
16%	frag.	3.92	1.98	3.23	Y	-2.66	-0.12	$\text{M} \to \text{E}$	$+2.66$	4.10	0.17
	mid.	1.97	1.86	1.30	Y	-1.39	-0.25	$\text{M} \to \text{E}$	$+1.39$	2.22	0.27
	rob.	0.57	1.57	0.75	n	$+0.99$	—	none	-0.99	0.00	0.00

blast death rate	stance	sev_m	sev_e	sev_g	riot	margin_m	margin_e	verdict	Φ	$\Delta\theta_m^{\text{rec}}$	$\Delta\theta_e^{\text{rec}}$
26.2%	frag.	3.92	2.00	2.34	Y	−2.66	−0.12	M → E	+2.66	4.10	0.18
	mid.	1.97	1.91	1.09	Y	−1.39	−0.27	M → E	+1.39	2.22	0.28
	rob.	0.57	1.70	0.66	n	+0.99	—	none	−0.99	0.00	0.00
36.4%	frag.	3.92	2.01	1.97	Y	−2.66	−0.12	M → E	+2.66	4.10	0.18
	mid.	1.97	1.95	0.91	n	−1.39	−0.28	M → E	+1.39	2.22	0.30
	rob.	0.57	1.82	0.61	n	+0.99	—	none	−0.99	0.00	0.00

S2C3 — U.S.–Great Power, 115 Tg:

blast death rate	stance	sev_m	sev_e	sev_g	riot	margin_m	margin_e	verdict	Φ	$\Delta\theta_m^{\text{rec}}$	$\Delta\theta_e^{\text{rec}}$
35%	frag.	4.27	2.02	6.10	Y	−2.97	−0.13	M → E	+2.97	4.42	0.18
	mid.	2.27	1.99	2.09	Y	−1.82	−0.29	M → E	+1.82	2.65	0.31
	rob.	0.86	1.90	1.16	Y	+0.32	—	none	−0.32	0.00	0.00
41%	frag.	4.27	2.02	5.72	Y	−2.97	−0.13	M → E	+2.97	4.42	0.18
	mid.	2.27	2.00	1.97	Y	−1.82	−0.29	M → E	+1.82	2.65	0.31
	rob.	0.86	1.94	1.05	Y	+0.32	—	none	−0.32	0.00	0.00
46.7%	frag.	4.27	2.02	5.26	Y	−2.97	−0.13	M → E	+2.97	4.42	0.18
	mid.	2.27	2.01	1.97	n	−1.82	−0.30	M → E	+1.82	2.65	0.31
	rob.	0.86	1.98	0.94	n	+0.32	—	none	−0.32	0.00	0.00

These cases correspond to the following logistic curves:

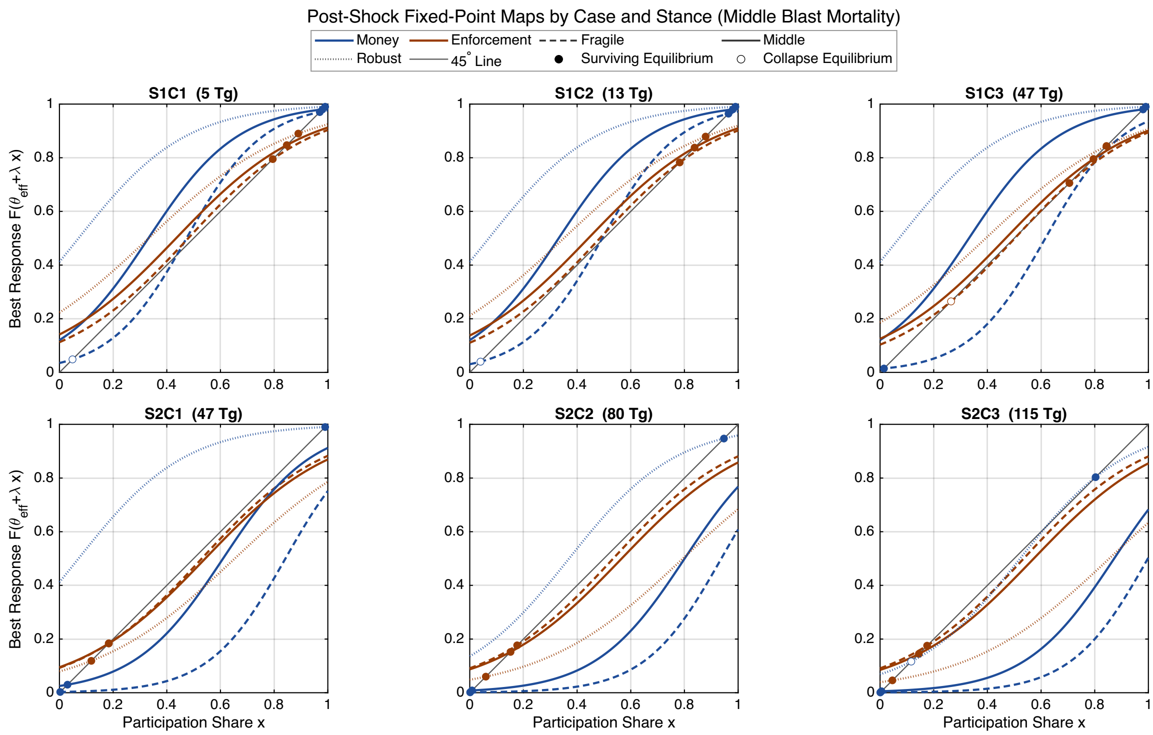

Figure 3: Post-shock fixed-point maps $F(\theta_{\text{eff}} + \lambda x)$ against the 45° line for money (blue) and enforcement (orange) under the three parameter stances and middle blast mortality. Filled markers denote the surviving equilibrium; where a curve crosses the line only near the origin, the institution has tipped.

Intersections with the 45° line constitute the equilibria. Filled markers near $(1, 1)$ denote the surviving (upper) equilibrium, while open markers denote the collapse equilibrium near the origin. The S1 panels show both institutions retaining their upper intersections at nearly all stances; in the S2 panels the curves fall progressively below the line. These curves are not to be confused with the general equilibrium "cliff" (Figure 2). They instead plot the best-response function $F(\theta_{eff} + \lambda x)$, which is a smooth logistic curve by construction. The cliff never lives in this curve; it lives in what happens to the intersection as the curve slides down: the tangency point where the upper intersection and the middle (unstable) intersection merge and vanish.

Recovery requirements (We have that $\Delta\theta^{\text{rec}} = |\text{breach}| + w$ (logit units), or that the depth of the fall past the tipping point plus the hysteresis overshoot must be surpassed to achieve θ^{restore}). Only cases in which an institution tips are shown, and we note that money's requirement is largely invariant to mortality level, while enforcement's fragility varies positively with it and is therefore reported in a range.

Money:

case	stance	breach_m	hysteresis w_m	$\Delta\theta_m^{\text{rec}}$
S1C3	frag.	0.30	1.45	**1.75**
S2C1	frag.	1.88	1.45	**3.33**
S2C1	mid.	0.24	0.83	**1.07**
S2C2	frag.	2.66	1.45	**4.10**
S2C2	mid.	1.39	0.83	**2.22**
S2C3	frag.	2.97	1.45	**4.42**
S2C3	mid.	1.82	0.83	**2.65**

Enforcement (breach and total recovery magnitude ($\Delta\theta_e^{\text{rec}}$) varies directly with mortality level (lower mortality $\Rightarrow$ lower magnitude):

case	stance	breach_e	hysteresis w_e	$\Delta\theta_e^{\text{rec}}$
S1C3	frag.	0.00–0.02	0.05	**0.05–0.07**
S2C1	frag.	0.10–0.11	0.05	**0.15–0.17**
S2C1	mid.	0.14–0.20	0.02	**0.16–0.22**
S2C2	frag.	0.12	0.05	**0.17–0.18**
S2C2	mid.	0.25–0.28	0.02	**0.27–0.30**
S2C3	frag.	0.13	0.05	**0.18**
S2C3	mid.	0.29–0.30	0.02	**0.31**

3.2 Interpretation

Three key results emerge. First, we see that the two overarching scenarios produce a drastically different set of outcomes for U.S. institutions, which is to be expected. Specifically, these institutions are highly unlikely to face any form of upheaval under the India–Pakistan scenario. They survive at the median and optimistic stances at every soot level, with the sole failure path emerging under 47 Tg of soot injection under the set of parameter values conducive to fragile U.S. institutions. Furthermore, our weak upper bound of 47 Tg somewhat exceeds most injection estimates within previous research on a regional nuclear altercation between these two states, with Jägermeyr et al. (2020) using 5 Tg as their anchor in a landmark study on the capacity for such a conflict to compromise *global* food security, and Toon et al. (2019) proceeding under a range of 16-36 Tg injected (reasons for our choice of 47 Tg are given in Section 1.1). Meanwhile, under the U.S.–Great Power scenario, institutional failure occurs under every median and pessimistic case, while the optimistic values result in institutional survival under all three rungs. This critical difference in results naturally follows from the extremely limited ~ 0 level of relevant U.S. infrastructural damage that would result from a conflict more than 7,000 miles away. Such a difference is visible in the following depiction of the fragility scenarios:

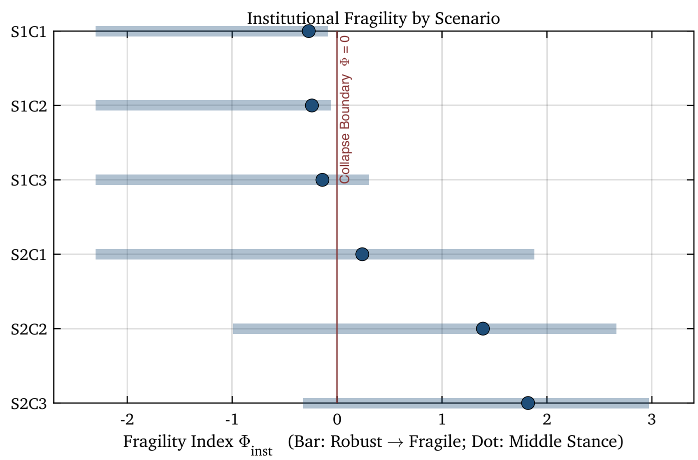

Figure 4: Fragility index Φ_{inst} by scenario ($\Phi > 0$: at least one institution tipped). Bars span the robust-to-fragile stances, while dots mark the middle stance. We see that almost all of the India–Pakistan cases sit left of the collapse boundary, while every U.S.–Great Power case crosses it at just the middle stance. However, parameter uncertainty visibly dominates each scenario's severity and the subsequent result.

and the heatmap:

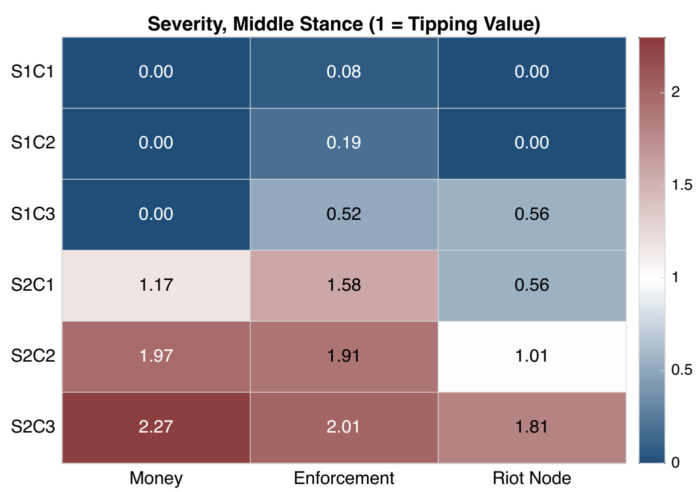

Figure 5: Normalized severities at the middle stance and middle mortality, with 1 equating to the tipping value in all cases. Enforcement binds first at 47 Tg, while money dominates the collapse cases for 80–115 Tg.

Second, the two institutions fail differently. Enforcement failure is more frequent, but also more shallow and ”easier” (in terms of the model) to reverse. Though damage severity exceeds one (i.e. tipping occurs) in every Scenario-2 median and pessimistic cell, driven primarily by infrastructural damage, restoration requirements never exceed 0.31 logit units in light of a small hysteresis gap following from a relatively low range of values comprising its complementarity parameter, λ_e. Meanwhile, while currency is considered to be the more ”stable” peacetime institution, resting much further from collapse at baseline, monetary failure yields a far higher $\Delta\theta^{\text{rec}}$ to the point of being quasi-irreversible without a discrete regime change. Indeed, restoration requirement runs 1.1–4.4 logits (up to three times the entire baseline margin). This difference is particularly visible in the following graph, which features the different recovery requirements (logits) under each failure scenario:

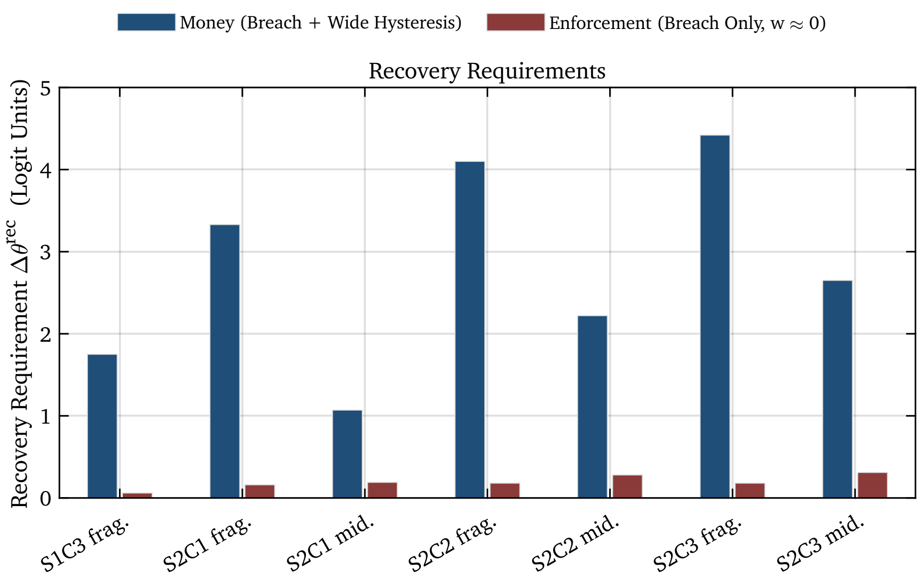

Figure 6: Restoration requirements $\Delta\theta^{\text{rec}}$ for every tipped case. Money's requirement runs 1.1–4.4 logits, while enforcement's (breach only) never exceeds 0.31. We take this asymmetry into account when offering policy prescriptions in Section 3.3.

Third, the food-riot node's output is largely a result of relative desperation (as measured by the expected increase in the share of income the 25th percentile household spends on food) rather than price increases alone, although the latter plays a key role in exacerbating the former. However, a riot-susceptible state is reached only when a collapse in incomes acts in tandem with a severe price shock. Lastly, it is worth noting that uncertainty regarding institutional parameters (and whether or not these are the critical components) dominates blast and weapon uncertainty throughout the model. These results are to be interpreted skeptically and cautiously, with the knowledge kept in mind that this model offers a flawed and incomplete description of institutional reality, at best.

3.3 Recommendations for Policy and Future Research

Section 3.2's results offer a natural ordering for policy priorities and recommendations. Monetary failure via hyperinflation is both rarer but quasi-irreversible (restoration requirement range of 1.1–4.4 logits getting up to several times the entire baseline margin), while enforcement failure is far more frequent but less politically severe. Hence, while we explicitly modeled both institutions to fail gradually, and then suddenly upon reaching the tipping point, the vastly different failure modes naturally warrant vastly different optimal policy responses. While money is ideally prevented from tipping by a specific measure held ready in advance (though we suggest that a monetary "regime change" remains technically feasible under a more extreme scenario), viable enforcement is restorable on the condition that the technological capacity to do so survives the shock. Hence, ensuring that this capacity indeed survives becomes the primary mechanism for maintaining viable enforcement. Lastly, we argue that the food-riot node is best addressed by reducing the conditions under which riots become rational.

For effective monetary policy, the comparatively large hysteresis gap resulting from monetary failure implies that no marginal intervention (i.e. a modest rate adjustment or open-market program) can restore a currency suffering from hyperinflation. A discrete change in the monetary regime itself is instead necessary for crossing the θ^{restore} threshold. Sargent's (1982) study of the ends of four great hyperinflations following WWI offers a useful policy template for our purposes. He notes that each episode ended abruptly after a credible and visible change in the fiscal-monetary regime, typically in the form of a newly independent monetary authority legally prevented from financing the deficit in any capacity with convertibility between the currency and a nonperishable commodity. The corresponding peacetime measure is simple and relatively inexpensive. Namely, a pre-legislated statutory authority for contingently pegging dollar to a commodity or specific commodity basket, activated upon a qualifying event, in addition to the reserve arrangements necessary for making this measure credible. The cost of such a peg, which effectively abandons monetary discretion amid a catastrophe, comes in the form of deflationary pressure and a deeper short-run recession than the counterfactual. The U.S.'s possession of more than 8,000 metric tons of official gold reserves alludes to a ready anchor for such a peg. The importance of the policy's timing is worth noting. Namely, the relative value of the peg is likely to covary positively along with when it binds. If activated before the unraveling of inflation expectations (i.e. before any portion of D_{fisc} exceeds the financeable borrowing capacity $b(s)$ and must instead be financed by printing money to express this dynamic in terms of the model), then the peg pins expectations while credibility still exists to be preserved, alluding to the prospect of a less severe pegging and contraction process. However, if activated after these expectations have unraveled, the same instrument must instead regain lost credibility, likely through a far steeper dollar to commodity ratio and harsher contraction. Hence, implementation under a trigger predetermined on the basis of observable conditions, rather than left to mid-crisis discretion, would greatly enhance the policy's value.

Enhancing the resilience of enforcement capabilities, while technically more "feasible" due to the closer distance between θ_e after the shock and $\theta_e^{\text{restore}}$ relative to that of monetary damage, presents its own set of challenges in light of the failure mode in the opposite direction (i.e. towards authoritarianism). Up until now, we have overwhelmingly considered the "leftward" failure mode for institutions (i.e. into non-compliance and anarchy). Doing so naturally follows from our treatment of a "stable" institution as one garnering widespread public compliance. However, the corridor in which institutions actually play a role in promoting the public good is bounded on both sides — between the anarchy we have sought to model and a coercive consolidation we have not — while the historical record suggests that the "rightward" exit may also pose a severe risk in the form of value lock-in under a coercive, expropriating government (Acemoglu & Robinson, 2019). Indeed, an authoritarian-oriented value lock-in could very well yield a worse outcome than the transient institutional collapse it was invoked to prevent (Bostrom, 2014). Higgs (1987) documents this precise mechanism in his comprehensive study of American crisis governance, whereby state capacity expands during war and states of emergency but does not return to prior levels after the emergency passes. This same concern applies to addressing the food-riot node. As sev_g falls whenever the state's capacity to suppress unrest rises (i.e. better riot equipment reduces coup risk precisely as effectively as stocked granaries do), the provision-side lever (visible reserves and distribution to reduce grievance) and the repression-side lever (to suppress its expression) are equivalent in the model's arithmetic. Our recommendations for maintaining enforcement viability are confined entirely to the former, as a discrete "regime change" of the kind we prescribe for monetary policy is neither a necessary condition here, in light of enforcement's far smaller hysteresis gap leaving restoration within reach of standard capacity enhancements, nor acceptable, in light of the cascading risks associated with value lock-in that accompany a coercive state.

Within those bounds, enforcement viability can be significantly improved by measures following directly from the institution's damage function. Deterrence literature consistently finds that a higher probability of apprehension is far more effective in reducing crime than the prospect of severe punishments (Nagin, 2013; Chalfin & McCrary, 2017). Hence, the fundamental margin of interest is detection capacity (modeled as $P(s)$ in our decomposition), with peacetime investments optimally being directed towards maintaining this capacity despite potential failure of the infrastructure that it currently relies on. This comes in the form of four subfamilies of investment. First, more redundant police communication networks such as EMP-shielded radio equipment and satellite-network backups to dispatch systems, as well as additional priority-access emergency networks such as FirstNet, would increase f_{disp} at all levels of s and E_{infra}. Second, a distributed backup for property and court case records, namely in the form of county deed registries, court dockets, and evidence chains duplicated at geographically separate sites and in formats that survive a grid failure with higher likelihood would significantly raise r_{records}. Third, pre-negotiated mobilization contracts, modeled on existing interstate mutual-aid arrangements, that specify in advance how National Guard units would supplement civilian policing and the chain of command would raise f_{mob} without leaving this question of command and control to be improvised in the worst month of the crisis. Fourth, continuity-of-operations planning for the court system would include pre-designated alternative facilities, a roster of alternative magistrates for hearing commercial disputes, and a simplified emergency procedure drafted and adopted in advance could maintain $C(s)$ above the level at which the contract backstop remains credible. None of these are novel instruments, and all four are cost-effective relative to the losses they insure against. Lastly, each measure should maintain constraints against coercive rule within their design and implementation. Such constraints may include, but are not limited to statutory sunset clauses imposing a non-negotiable expiration date on the emergency legislation, the preservation of judicial review, and detection capabilities targeted towards detecting predatory violation rather than simply surveilling much of the population.

Government could also play a significant role in increasing food provisions. First, pre-authorized regulatory rollback should exist. Relevant examples of reducing current regulation inhibiting food production include the contingent release of Conservation Reserve Program acreage ($\sim$ 20 million acres currently held out of production) for immediate planting, a pre-cleared emergency approval pathway for novel food products such that lignocellulosic sugar and single-cell protein do not spend six months in regulatory review, automatically waiving the requirement for occupational licensing for food-chain and food-production labor, as well as extremely expedited permitting (if not elimination of the requirement for a permit) for repurposing industrial facilities for food production. None of these measures require weakening safety oversight in peacetime. Rather, they entail currently deciding upon what legislation is to be suspended in the future to not waste crucial human capital on making and voting on straightforward repeals in the first months of the scenario. Second, existing analyses find resilient-food R&D to be perhaps the most cost-effective catastrophe intervention (Denkenberger et al., 2022), but it has attracted negligible public and private investment thus far. This outcome is not surprising, as the value of such R&D is only realized under a low-probability event, with expected-value reasoning over such a state of the world being neither intuitive nor rewarded by any market. Hence, current investment in this public good, with specific emphasis on scaling technology and doing so under compromised infrastructure, could be led by government. Third, developing a strategic grain reserve, even in limited capacity, has proved to be effective policy, especially during the 2007–08 food price spikes, when drought-stricken African countries that maintained functioning stocks weathered the crises significantly better than neighbors without the same reserve capacity (Demeke et al., 2009). Similar to the other two policy measures discussed above, building and maintaining some reserve capacities is cheap relative to the quasi-irreversible institutional failures they buffer against. However, stockpiling it is expensive relative to the other measures and may also exacerbate current food insecurity by siphoning foodstuffs away from current consumption (Denkenberger & Pearce, 2014). Lastly, imposing foodstuff export controls may be a necessary precaution for ensuring that U.S. producers do not sell to overseas buyers who may now possess comparatively higher purchasing power at the expense of domestic needs.

For future research directions, the breadth of our confidence intervals alludes to a logical next step of reducing the uncertainty within our institutional parameters, which dominates the uncertainty regarding technical blast damage throughout the model and within subsequent results. Two factors in particular, namely the expected change in prices ($P(s)$ and $\pi(s)$) and infrastructural damage (E_{infra}), influence the variation in results to a far greater degree than we would like. The work on prices ought to go beyond extrapolating from Hinge et al. (2026) towards actually deriving demand functions for staple crops to achieve a stronger estimate of demand elasticities and the subsequent price increases under a negative shock to supply via conventional methods. Meanwhile, the infrastructure refinement entails enhancing our admittedly rudimentary treatment of food-production infrastructure, to also account for sector-level modeling and fertilizer production in greater detail. Second, and urgently, mitigating drift towards the "rightward" side of the institutional corridor under a nuclear winter scenario likewise deserves extensive treatment. This research would likely come in the form of modeling the state's coercive expansion to understand what distinguishes the states that reverted back to normal governance after a crisis from those that did not. Third, the peacetime-investment logic warrants further justification by an explicit cost-benefit analysis of node-strengthening measures. Considering the dollar cost per unit of restored margin, compared across the monetary, enforcement, and provision investments recommended above would raise the probability of actual investment under a fixed peacetime budget, revealing which margin is cheapest to widen and therefore where the next dollar of spending should actually go. Fourth, and lastly, the model should be expanded to consider the institutional prospects for other countries. We have calibrated to the United States for reasons of data provenance and of the U.S.'s presence in both the international food system and many plausible nuclear exchanges, but it is among the least institutionally exposed countries in the set, featuring comparatively less compromised agricultural production and far greater fiscal capacity (though other afflicted countries will likely be more capable of a currency change in the wake of hyperinflation). Hence, extending the calibration to import-dependent, low-reserve countries featuring different binding constraints, as well as providing policy recommendations that address these expected changes in international trade and immigration would expand this research from an instrument serving the national-security interests of the U.S. to one that benefits humanity more generally.

APPENDIX A: Formal Derivations

Throughout, drop the institution subscript i and keep ϵ general (as opposed to setting it to unity). Recall $G(x,\theta) = F(\theta+\lambda x)-x$ with $F(z) = \left(1+e^{-z/\epsilon}\right)^{-1}$. Equilibria solve $G = 0$; under the best-response adjustment dynamic, an equilibrium is stable iff $\partial G/\partial x = \lambda F'(\theta + \lambda x) - 1 < 0$.

A.1 The Maximal Slope of the Logistic Response

Differentiating F,

$$F'(z) = \frac{1}{\epsilon} \cdot \frac{e^{-z/\epsilon}}{\left(1 + e^{-z/\epsilon}\right)^2} = \frac{1}{\epsilon}\, F(z)(1 - F(z)),$$

where the second equality follows from $F(z) = \left(1 + e^{-z/\epsilon}\right)^{-1}$ and $1 - F(z) = e^{-z/\epsilon}\left(1 + e^{-z/\epsilon}\right)^{-1}$. Writing $u = F(z) \in (0, 1)$, the slope is $\frac{1}{\epsilon}u(1 - u)$, and the quadratic $u(1 - u)$ is maximized at $u = \frac{1}{2}$ (its derivative $1 - 2u$ vanishes there, with second derivative $-2 < 0$), where it attains $\frac{1}{4}$. Hence

$$F'_{\text{max}} = \frac{1}{4\epsilon}, \qquad \text{attained at } z = 0, \text{ i.e. } F(z) = \tfrac{1}{2}.$$

This bound delivers the bistability gate quoted in the text: a saddle-node tangency requires $\lambda F' = 1$ at some fixed point, which is achievable iff $F'_{\text{max}} \geq 1/\lambda$, i.e. iff $\lambda \geq 4\epsilon$. Below the gate no tangency exists, $G = 0$ has a unique fixed point, and the institution degrades smoothly with θ; above it, two stable fixed points and an unstable middle fixed point coexist over an interval of θ.

A.2 Inverse and the θ-Locus

From $x = F(z)$ we obtain $e^{-z/\epsilon} = \frac{1-x}{x}$, so $z = \epsilon \ln \frac{x}{1-x} = F^{-1}(x)$. At any fixed point $\theta + \lambda x = F^{-1}(x)$, hence every equilibrium lies on the locus

$$\theta(x) = \epsilon \ln \frac{x}{1 - x} - \lambda x. \tag{A.1}$$

A.3 The Fold (Saddle-Node) Condition

A fold is a fixed point at which the response curve is additionally tangent to the 45° line: $\partial G/\partial x = 0$, i.e. $\lambda F' = 1$.

Using $F' = F(1 - F)/\epsilon$ from A.1 and $F = x$ at a fixed point, the tangency condition reads $\lambda x(1 - x)/\epsilon = 1$, i.e. $x(1 - x) = \epsilon/\lambda$, whose roots are the two fold states

$$x_\pm = \frac{1 \pm \sqrt{1 - 4\epsilon/\lambda}}{2}, \tag{A.2}$$

real iff $\lambda \geq 4\epsilon$ — the same gate derived in A.1. The upper fold x_+ (near 1) is the knee at which the functioning branch dies (the tip); the lower fold x_- (near 0) is the knee at which the collapse branch dies (the restore). Substituting (A.2) into (A.1) yields the closed forms quoted in the text:

$$\theta^{\text{tip}} = \epsilon \ln \frac{x_+}{1 - x_+} - \lambda x_+, \qquad \theta^{\text{restore}} = \epsilon \ln \frac{x_-}{1 - x_-} - \lambda x_-. \tag{A.3}$$

A.4 Branch-Tracking and the Discontinuous Jump

On a stable branch $\partial G/\partial x \neq 0$, so the implicit function theorem gives a smooth equilibrium path $x^*(\theta)$ with

$$\frac{dx^*}{d\theta} = -\frac{\partial G/\partial \theta}{\partial G/\partial x} = -\frac{F'(\theta + \lambda x^*)}{\lambda F'(\theta + \lambda x^*) - 1}.$$

The attracting branch therefore drifts smoothly as θ moves — until a fold, where $\partial G/\partial x \to 0$ and $dx^*/d\theta \to \infty$ (vertical tangent): the stable branch and the unstable middle branch collide and annihilate, and the state falls discontinuously to the sole remaining branch. Lowering θ, the system rides the upper branch to its knee at θ^{tip} and drops; raising θ, it rides the lower branch to its knee at θ^{restore} and jumps back up. The asymmetry of the two paths is the model's hysteresis.

A.5 The Hysteresis Width Is Strictly Positive

Let $a = \sqrt{1 - 4\epsilon/\lambda} \in [0, 1)$, so that $x_+ = \frac{1+a}{2}$, $x_- = \frac{1-a}{2} = 1 - x_+$, and

$$\ln \frac{x_+}{1 - x_+} = \ln \frac{1+a}{1-a} = 2 \operatorname{arctanh} a, \qquad \ln \frac{x_-}{1 - x_-} = -2 \operatorname{arctanh} a,$$

while the definition of a gives $4\epsilon = \lambda(1 - a^2)$. Subtracting the two lines of (A.3),

$$\theta^{\text{restore}} - \theta^{\text{tip}} = \left(-2\epsilon \operatorname{arctanh} a - \lambda \tfrac{1-a}{2}\right) - \left(2\epsilon \operatorname{arctanh} a - \lambda \tfrac{1+a}{2}\right) = \lambda a - 4\epsilon \operatorname{arctanh} a,$$

and substituting $4\epsilon = \lambda(1 - a^2)$,

$$\theta^{\text{restore}} - \theta^{\text{tip}} = \lambda\big[a - (1 - a^2) \operatorname{arctanh} a\big] =: \lambda\, h(a). \tag{A.4}$$

It remains to sign h. Clearly $h(0) = 0$, and using $\frac{d}{da} \operatorname{arctanh} a = \frac{1}{1-a^2}$,

$$h'(a) = 1 - \big[-2a \operatorname{arctanh} a + 1\big] = 2a \operatorname{arctanh} a > 0 \quad \text{for } a \in (0, 1),$$

so h is strictly increasing from 0 and $h(a) > 0$ on $(0, 1)$. Hence, we have that $\theta^{\text{restore}} - \theta^{\text{tip}} = \lambda\, h(a) > 0 \quad$ whenever $\lambda > 4\epsilon$. $\square$

APPENDIX B: Data Provenance, Parameter Explanation

Baseline Participation Shares

Money, $x_m^{*0} = 0.98$ ($[0.97, 0.99]$). The U.S. dollar currently serves as the world's dominant reserve currency, and the Federal Reserve's independence consistently anchors inflation near its target of 2%. These features sustain a near-universal transactional demand for the currency, with only a fairly high federal debt-to-GDP ratio of approximately 120% leaving baseline participation at a level just below unity.

Enforcement, $x_e^{*0} = 0.85$ ($[0.80, 0.89]$). No single statistic adequately captures the baseline "participation share" for contract and property-rights enforcement, so we construct this value as a composite of three sub-indicators. The first is *formality*, defined as one minus the share of economic activity conducted in the shadow economy completely unmonitored by the U.S. government, currently estimated to constitute 6–7.6% of GDP; formality thus sits at approximately 0.92–0.94, representing the fraction of exchange that takes place inside the enforceable economy rather than requiring self-help. The second is *enforcement quality*, drawn from the World Justice Project's 2025 Rule of Law Index, whereby the United States' middling ranks—37th of 143 on civil justice and 27th of 143 on regulatory enforcement—correspond to underlying scores of roughly 0.60–0.73, which we gauge as the reliability with which existing contracts are actually adjudicated and enforced. The third is *criminal efficacy*, proxied by the homicide clearance rate of 57.8%—the fraction of severe violations that are actually solved and punished—which we take directly as a value of ≈ 0.58; property-crime clearance ($\sim$14%) is deliberately excluded as non-diagnostic, since the relatively limited investigation of petty theft reflects triage more than any form of institutional failure. Aggregating these three across plausible weighting schemes yields a central value of $x_e^{*0} \approx 0.85$, with the width of the interval dominated by our treatment of formality as the anchor, which pushes the estimate toward a higher value.

Complementarity

The response function depends on $(\theta_i, \lambda_i, \epsilon)$ only through the ratios θ_i/ϵ and λ_i/ϵ. Hence, one degree of freedom is redundant, and we normalize $\epsilon = 1$ such that only λ_i/ϵ is identified from aggregate tipping and hysteresis behavior. Separating ϵ—the relative heterogeneity of individual switching thresholds—from λ would require micro-data on that dispersion, which we lack, so the λ_i are elicited rather than estimated. We assign $\lambda_m \approx 6.0$ (interval $[5, 7]$) and $\lambda_e \approx 4.15$ ($[3.75, 4.3]$), each set against the bistability gate $\lambda_i > 4\epsilon = 4$, below which an institution has a single fixed point and merely degrades smoothly rather than tipping.

The ordering $\lambda_m > \lambda_e$ is supported by verbal argument, although the exact levels are priors. Money takes the largest value by virtue of being the purest coordination good (a currency's value being entirely contingent on others accepting it), and of flight from money being self-accelerating: as holders exit, inflation rises, sharpening every remaining holder's incentive to exit, so we place the widest hysteresis loop on it. The viability of enforcement, while not yielding as strong a network payoff as a stable currency, is enhanced by the expectation that others will honor contracts, suggesting a real but weaker complementarity value of $\sim$4.15. Legitimacy's complementarity would be the least certain of the three, which is part of why we treat the riot node as a threshold condition rather than a full tipping institution (Section 2.4). On one hand, it is prone to standard network-complementarity effects, whereby individuals comply while believing others support the regime and then defect suddenly and en masse once they perceive others doing the same, which would place its complementarity high. On the other hand, legitimacy has substantial *idiosyncratic anchoring* that money and enforcement lack: compliance is sustained not only by what others do but also by elements of an individual's identity, which are non-contingent and dampen the aggregate cascade.

Scenario-Level Function Values, Parameter Justification

The six scenarios are labeled S1C1–S1C3 (India–Pakistan at 5, 13, and 47 Tg) and S2C1–S2C3 (U.S.–Great Power at 47, 80, and 115 Tg). All cells report the center of the [90% CI] that we have determined. Further justification is offered in the corresponding damage-function sections.

Key Values:

	$g(s)$ (GDP loss)	$m(s)$ (blast mortality)	disp(s) (displaced)	pop(s) (millions)
S1C1	0.02 [0.01, 0.04]	0	0	342.7
S1C2	0.05 [0.03, 0.08]	0	0	342.7
S1C3	0.15 [0.10, 0.25]	0	0.015 [0, 0.03]	342.7
S2C1	0.30 [0.20, 0.40]	0.12 [0.09, 0.16]	0.15 [0.08, 0.25]	300.2 [287.7, 312.7]
S2C2	0.50 [0.40, 0.65]	0.26 [0.16, 0.36]	0.25 [0.15, 0.38]	252.7 [217.7, 287.7]
S2C3	0.70 [0.55, 0.80]	0.41 [0.35, 0.47]	0.30 [0.20, 0.45]	202.7 [182.7, 222.7]

Monetary Damage Function

We linearize the expected federal deficit in the wake of a nuclear winter scenario by $D_{\text{fisc}} \approx d_0 + \kappa_{\text{rev}} g(s) + e_{\text{emg}}(s)$. $d_0 \approx 0.06$, as the current projected US federal budget deficit constitutes 5.8% of GDP for fiscal year 2026 (CBO, 2025). **[D]**. We have that $\kappa_{\text{rev}} \in [0.20, 0.35]$. As κ_{rev} corresponds to the passive percentage-point increase in deficit/GDP ratio for each point of GDP lost, it's expressed as the product of the revenue-to-GDP ratio and revenue-to-GDP elasticity. The former term approximates .30 for all levels of the U.S. government, with the federal level contributing $\sim$ .18 of this value, while the latter value is estimated to fall within the range of $[1.2, 2.0]$, as the more cyclical bases contributing to revenue (namely capital gains) collapse faster than GDP. Hence, the product yields a confidence interval of $\sim [.20, .36]$. As noted previously, $g(s)$ is the expected loss in GDP resulting from the shock. Meanwhile, e_{emg} corresponds to discretionary emergency spending, as a share of post-shock GDP. The function is notably not a smooth, generalizable function of the downturn but instead a policy-contingent term.

For magnitude, the modern financial record brackets the term: the COVID-19 fiscal response peaked near 13% of GDP in a single fiscal year (CBO, FY2020: deficit 14.9% of GDP against a $\sim 4.6\%$ structural baseline), while the WWII mobilization peak, which featured federal outlays $\sim 44\%$ of GDP in 1944 against a $\sim 10\%$ prewar norm (OMB Historical Tables 1.2), sets a hard ceiling near $+30$ points of GDP. Because emergency spending is policy-contingent and scales with the disaster confronted, we scale the interval by scenario rather than holding it fixed: minimal agricultural-support packages in S1C1–S1C2 (centers 0.01–0.03, comparable to the farm-support and disaster-relief tranches of 2008–09 and 2020), a substantial response at S1C3 (center 0.08, COVID-order), and mobilization-scale responses across S2 (centers 0.20–0.22, bounded above by the WWII ceiling of 0.30), with the resilient-food scale-up itself remaining comparatively minor ($\sim$\$500B $\approx 2\%$ of GDP; Denkenberger et al., 2022).

Next, we consider the financeability function: $b(s) = f_{\text{plumb}}(E_{\text{infra}}) \cdot [b_{\text{dom}} + b_{\text{for}} I_{\text{reserve}}]$. For domestic absorption, b_{dom}, which corresponds to the net issuance that domestic savers will hold each year without demanding a significant yield increase. For the lower bound of our confidence interval, we know that the domestic market has historically absorbed net federal issuance at a rate of $\sim$ 10% of GDP per year. Meanwhile, when savers reallocate sharply towards treasuries during periods of tension, the absorption rate has naturally increased, such as during 2020, when a $\sim$15%-of-GDP deficit was absorbed by creditors at a $\sim$1% yield in the wake of the pandemic. We'll add an additional 10% "extremity buffer" to this datum to yield a confidence interval of $b_{\text{dom}} \in [0.10, 0.25]$. For foreign absorption, we know that international state and non-state investors hold $\sim 33\%$ of U.S. Treasury bonds, while the foreign rate of issuance is typically between 2% and 5% of U.S. GDP per year. Hence, we offer $b_{\text{for}} \in [0.02, 0.10]$ as a confidence interval. Our binary reserve value, $I_{\text{reserve}} \in \{0, 1\}$ is a probability-weighted switch. During a standard crisis that cannot be at least indirectly attributed to the

U.S. government, the dollar strengthens as more and more capital and savings are directed towards treasury bonds. However, during a U.S.-centric crisis, this reflex would likely invert, leading foreigners to dispose of Treasury holdings, gradually driving down I_{reserve} to 0. Hence, we'll treat it as a binary switch between the two regimes, which we set to ~ 1 under the India-Pakistan scenario and ~ 0 under the U.S.-Great Power scenario.

Operational plumbing, $f_{\text{plumb}}(s) \in [.1, 1]$, corresponds to the fraction of technical U.S. Treasury-market functions that survive the physical blast damage. We'll treat it as the maximum of .1 (assuming that a reduced level of credit would persist through rudimentary transactional methods even under an extreme nuclear winter scenario) and the product of the survival of four subsystems: electricity, settlement via commercial telecommunications networks such as Fedwire, ownership records, and dealer intermediation through the ~ 25 primary banks obligated to bid at treasury auctions such that

$$f_{\text{plumb}}(s) = \max\{.1, f_{\text{elec}}(s) \cdot f_{\text{settle}}(s) \cdot f_{\text{own}}(s) \cdot f_{\text{deal}}(s)\}.$$

Overwhelmingly influenced by the infrastructural damage component of s (as opposed to soot), it is reasonable to expect the function's output to remain at ~ 1 in the case of a regional India-Pakistan nuclear altercation and fall precipitously with each increase in blast magnitude under the U.S.-Great Power scenario. Restricting focus to the three cases within this scenario yields: **Treasury-Market Plumbing** ($f_{\text{plumb}}(s) = \max\{.1,\ f_{\text{elec}} \cdot f_{\text{settle}} \cdot f_{\text{own}} \cdot f_{\text{deal}}\}$):

	f_{elec}	f_{settle}	f_{own}	f_{deal}	$f_{\text{plumb}}(s)$
S1C1	1.00	1.00	1.00	1.00	1.00 [0.97, 1]
S1C2	1.00	1.00	1.00	1.00	1.00 [0.95, 1]
S1C3	1.00	0.99	1.00	0.98	0.97 [0.90, 1]
S2C1	0.85 [0.70, 0.95]	0.85 [0.70, 0.95]	0.95 [0.90, 1]	0.90 [0.80, 0.95]	0.62 [0.50, 0.80]
S2C2	0.50 [0.30, 0.65]	0.50 [0.30, 0.65]	0.85 [0.70, 0.95]	0.60 [0.40, 0.75]	0.13 [0.10, 0.35]
S2C3	0.20 [0.05, 0.35]	0.25 [0.10, 0.40]	0.70 [0.50, 0.85]	0.35 [0.15, 0.50]	0.10

Justification. *Electricity* f_{elec}: the EMP Commission (Foster et al., 2008) concludes that even a limited high-altitude event could deny power to a large fraction of the grid for several months; our S2 values scale the share of generating and transmission capacity within struck regions, with S2C3's 0.20 reflecting near-total loss of Eastern and Western interconnections resulting from quasi-defective urban load centers. *Settlement* f_{settle}: Fedwire and NSS clear through a small number of Federal Reserve data centers, and DTCC settlement is similarly concentrated in the New York metropolitan area – a concentration risk demonstrated by the 9/11 settlement disruption (Fleming & Garbade, 2002, FRBNY *Economic Policy Review*), when Treasury settlement fails spiked for weeks after damage to lower Manhattan alone. *Ownership records* f_{own} is the most survivable component: Treasury ownership is analog book-entry featuring geographically separated backup facilities (as mandated by the post-9/11 ”sound practice” interagency requirements). *Dealer intermediation* f_{deal}: all ∼25 primary banks obligated to bid at auction are headquartered or operate in Manhattan. The fairly precipitous dropoff reflects both personnel loss and the demonstrated fragility of auction demand under stress (the March 2020 Treasury-market dysfunction, whereby dealer intermediation broke down without any physical damage; Duffie, 2020). The general floor of 0.10 encodes Brown's (1968) finding that rudimentary means of manual clearing and exchange persist and is recoverable at cost even under severe attack scenarios.

As a point of reference and model sanity check, we have that baseline financeability, b_0, approximates 0.24. At $s = 0$, every parameter in the financeability function rests at its healthy level, whereby $f_{\text{plumb}} = I_{\text{reserve}} = h = 1$, such that b_0 collapses to the pure demand sum $b_{\text{dom}} + b_{\text{for}}$. Summing the component intervals ($b_{\text{dom}} \in [0.10, 0.25]$ and $b_{\text{for}} \in [0.02, 0.10]$) yields baseline financeability $b_0 \in [0.12, 0.35]$, centered near 0.24.

Data supports this construction: in fiscal year 2020 the U.S. financed a federal deficit of roughly 15% of GDP while ten-year yields fell to near one percent, an indication of increased demand for holding U.S. debt and for saving more broadly. Hence, at the margin, realized absorption (b_0) was at least 0.15. Similarly, during WWII, fiscal deficits above 20% of GDP were financed through intense credit expansion, suggesting that our $b_0 \approx .24$ could even be a slightly conservative baseline.

Lastly, and crucially for deficit severity, is the monetized-deficit ceiling of $d^* \approx 0.20, \in [0.15, 0.25]$, which simply corresponds to the percentage threshold, beyond which the monetized deficit demands more revenue than can be raised by an inflation tax effective at any rate, and the government, chasing a necessarily receding target, drives inflation to accelerate without bound. Meanwhile, a monetized deficit below the peak (whereby D_{fisc} is sufficiently low or b sufficiently high such that $D_{\text{fisc}} - b < d^*$) yields a stable (albeit unpleasant) inflation equilibrium. Economist Thomas Sargent's (1982) study of four interwar hyperinflations (Austria, Hungary, Poland, Germany) provides the empirical anchor: the monetized deficits that destroyed those currencies ran in the range of 15–25% of GDP (Germany's Reich deficit exceeded half of expenditure, on the order of $20\%+$ of national income by 1922–23), and the broader high-inflation record surveyed by Fischer, Sahay & Végh (2002) finds no sustained monetization above $\sim 25\%$ of GDP without unbounded inflation.

Enforcement Damage Function

Prices, Income, and Second-Order (i.e. Post-Detonation) Survival:

	$\pi(s)$ (staple multiple)	$P(s)$ (survival basket, \$/yr)	$y(s)$ (25th-pct income)	$p_{\text{surv}}(s)$
S1C1	1.2 [1.1, 1.3]	660 [605, 715]	22,000 [21,000, 22,400]	1.00 [0.995, 1]
S1C2	1.45 [1.3, 1.6]	800 [715, 880]	21,200 [20,300, 21,900]	0.99 [0.98, 1]
S1C3	3.75 [2.5, 5]	2,060 [1,375, 2,750]	18,500 [16,200, 20,300]	0.96 [0.91, 0.99]
S2C1	6 [4, 8]	3,300 [2,200, 4,400]	16,900 [13,500, 19,500]	0.90 [0.82, 0.96]
S2C2	12.5 [10, 15]	6,875 [5,500, 8,250]	13,800 [10,000, 17,000]	0.80 [0.68, 0.90]
S2C3	20 [15, 25]	11,000 [8,250, 13,750]	9,200 [5,500, 13,500]	0.65 [0.50, 0.80]

(Here $y(s)$ is computed per capita, with the GDP contraction assessed against the *surviving* population: $g_{pc}(s) = 1 - (1 - g(s))/(1 - m(s))$, so that population loss partially offsets output loss in per-capita terms.)

Justification. *Staple multiple* $\pi(s)$. The S1 values interpolate the equilibrium model of Hinge et al. (2026), which prices a $\sim$16 Tg injection (11–23% yield loss) at 1.7–$1.9\times$ and $\sim$47 Tg (43–52%) at 10–$13\times$ for *world* cereals; our U.S. multiples sit well below the world figures in light of the U.S. being a large net exporter whose domestic prices are insulated by export reduction (documented in Martin & Anderson (2012) for 2007–08, when world grain prices roughly doubled while U.S. retail food inflation ran 5.5%; BLS CPI), because the feed-and-ethanol diversion buffer exceeds a year of national calories (Denkenberger & Pearce, 2014), and because the farm share of the U.S. retail food dollar is only $\sim$15.9 cents (USDA ERS, Food Dollar Series). The S2 values remove this insulation. The production collapse consumes the diversion buffer, in addition to processing and transport margins increasing with fuel scarcity such that multiples converge toward and beyond the world-price trajectory; the historical ceiling observations are based on Tambora-era regional grain prices ($\sim 3\times$; Post, 1977) and siege episodes exceeding $10\times$. *Survival basket* $P(s)$ arithmetically follows:

$c_{\text{subsist}} \cdot \pi(s)$, with $c_{\text{subsist}} = \$550$/yr constructed as the cheapest 1,800 kcal/day basket (rice, beans, oil, fortified flour) at 2025 national-average retail unit prices (BLS average price data; Walmart/USDA Thrifty Food Plan cross-check. The TFP itself, at ~$3,500/yr, buys palatability and variety far above the survival floor). *Income* $y(s)$ is arithmetic from $y_0 = \$22{,}500$ (Census CPS ASEC, 25th percentile of personal income, 2024) via $y(s) = y_0(1 - \gamma_y g_{pc}(s))$; the gearing $\gamma_y = 1.2$ $[1.0, 1.5]$ reflects the consistent finding that bottom-quartile incomes fall more than proportionally during economic contractions (in 2007–09, employment losses concentrated in the bottom wage quintiles; CBO distributional series and Chetty et al.'s time-series data in 2020 show low-wage employment falling at $\sim 4\times$ the aggregate). *Famine survival* $p_{surv}(s)$ is only through the agricultural channel (blast deaths enter via $m(s)$): values follow the no-adaptation famine mortality of Xia et al. (2022), scaled to the U.S. caloric balances of the Legitimacy Inputs table: S1 cases keep production above need (survival ≈ 1), while S2C3's 0.65 $[0.50, 0.80]$ reflects median production of ~1,450 kcal/cap/day against an 1,800 kcal need, partially offset by limited food storage and diversion.

Policing Personnel and Military Augmentation:

	$m_{\text{urban}}(s)$	$d_{\text{officer}}(s)$	$d_{\text{judge}}(s)$	mil(s)
S1C1	0	0.00 [0, 0.01]	0.00 [0, 0.01]	0 [0, 0.05]
S1C2	0	0.00 [0, 0.01]	0.00 [0, 0.01]	0 [0, 0.05]
S1C3	0	0.00 [0, 0.01]	0.00 [0, 0.01]	0.10 [0, 0.30]
S2C1	0.14 [0.09, 0.20]	0.20 [0.12, 0.30]	0.15 [0.08, 0.25]	0.15 [0.05, 0.35]
S2C2	0.28 [0.18, 0.38]	0.28 [0.18, 0.40]	0.25 [0.15, 0.38]	0.10 [0, 0.25]
S2C3	0.44 [0.36, 0.52]	0.35 [0.25, 0.45]	0.35 [0.25, 0.50]	0.05 [0, 0.20]

Justification. *Urban officer mortality* $m_{urban}(s)$ exceeds general mortality $m(s)$ in every S2 cell because sworn officers are disproportionately stationed in the large metropolitan areas that would disproportionally suffer from countervalue targeting. *Attrition* $d_{officer}(s)$ adds non-fatal loss, which may result from desertion in favor of family protection, non-payment, and injury, for which the cleanest modern dataset derives from Hurricane Katrina: ~15% of NOPD (~220 of 1,450 officers) were absent without leave within days of a *localized*, non-nuclear disaster (U.S. House, *A Failure of Initiative*, 2006); our S2 centers (0.20–0.35) scale that observed single-city rate to nationwide catastrophe with pay-system failure. *Judicial attrition* $d_{judge}(s)$ runs slightly below officer attrition at each level (judges are older but less field-exposed, and courts concentrate in county seats rather than exclusively in struck metropolitan areas). *Military augmentation mil*(s): the ceiling is set by force size ($\sim$1.3M active duty plus $\sim$ 0.8M National Guard and reserves (DoD personnel reports) against 708k police), though discounted for continuity-of-government, air/missile defense, and overseas commitments. The decline of this center across S2C1$\rightarrow$S2C3 (0.15$\rightarrow$0.05) results from the surviving military being either decimated or fully absorbed by core defense missions within larger exchanges.

Enforcement Technology:

	$f_{\text{disp}}(s)$	$f_{\text{mob}}(s)$	$r_{\text{pol}}(s)$
S1C1	1.00 [0.99, 1]	1.00 [0.99, 1]	1.00 [0.99, 1]
S1C2	1.00 [0.98, 1]	1.00 [0.98, 1]	1.00 [0.98, 1]
S1C3	1.00 [0.97, 1]	0.97 [0.97, 1]	1.00 [0.97, 1]
S2C1	0.60 [0.45, 0.75]	0.70 [0.55, 0.82]	0.80 [0.65, 0.90]
S2C2	0.35 [0.20, 0.50]	0.40 [0.25, 0.55]	0.60 [0.45, 0.75]
S2C3	0.15 [0.05, 0.25]	0.20 [0.08, 0.32]	0.40 [0.25, 0.55]

Justification. *Dispatch and vehicular capacity* $f_{disp}(s)$ largely derives from fuel and communications capacities. U.S. refining capacity is concentrated in a small number of Gulf Coast and coastal complexes (EIA, with reports finding that the top ten sites alone exceed a quarter of national throughput), so S2 strikes on industrial targets curtail patrol fuel within weeks, while 911/PSAP dispatch and radio infrastructure depend on grid power and backhaul that the EMP Commission (Foster et al., 2008) assesses as failing regionally; S2C3's 0.15 approximates foot-patrol-only policing outside surviving enclaves. *Mobilization* $f_{mob}(s)$ tracks the fraction of surviving personnel who can be organized and directed, and is likewise degraded by the same communications loss plus displacement of officers' families; its S2 centers sit modestly above f_{disp} in light of mobilization proceeding by station-level muster even where dispatch cannot. *Retention* $r_{pol}(s)$ is the share of mobilizable officers who continue serving as pay and pensions fail; the Katrina AWOL datum ($\sim$0.85 retention under localized stress) anchors the S2C1 center of 0.80, with subsequent values reflecting the post-Soviet experience, whereby police salary collapse produced mass exit into private security (Varese, 2001).

Court Operability:

	$f_{\text{facility}}(s)$	$r_{\text{records}}(s)$
S1C1	1.00	1.00
S1C2	1.00	1.00
S1C3	1.00 [0.98, 1]	1.00
S2C1	0.85 [0.75, 0.95]	0.85 [0.70, 0.95]
S2C2	0.65 [0.50, 0.80]	0.60 [0.45, 0.75]
S2C3	0.45 [0.30, 0.60]	0.40 [0.25, 0.55]

Justification. *Facilities* $f_{facility}(s)$: the U.S. operates courthouses in essentially all ∼3,100 counties, the vast majority in county seats outside major-metro blast radii, which keeps even S2C3 at 0.45 $[0.30, 0.60]$. That is, the physical plant of adjudication is far more dispersed than the financial system's. *Records* $r_{records}(s)$: land title, liens, and case records are county-held, with most populous counties completed digitization with offsite or cloud backup over the 2000s–2010s, but originals and servers for the largest metros sit in struck areas, and backup capacity within rural counties is again highly uneven (PRIA county-recorder surveys). Hence, S2 centers ($0.85/0.60/0.40$) reflect metro-share-weighted loss of authoritative records, which we treat as binding within adjudication capacity in light of a court without records being able to convene but not resolve competing claims. Post-conflict property-restitution literature (e.g., Bosnia, where destroyed cadastral records delayed restitution for a decade) demonstrates the bottleneck adequately.

Legitimacy Inputs (Caloric Balance):

	need(s) (millions kcal)	supply(s) (millions kcal)	kcal/cap/day
S1C1	225,153,900	1,500,000,000 $[1.40, 1.60]\times10^9$	∼12,000
S1C2	225,153,900	1,350,000,000 $[1.20, 1.50]\times10^9$	∼10,800
S1C3	225,153,900	800,000,000 $[0.60, 0.95]\times10^9$	∼6,400
S2C1	188,770,200 – 205,153,200	487,833,450 [243,916,725, 691,097,388]	4,274–4,645
S2C2	143,028,900 – 188,770,200	232,533,945 [121,958,363, 365,875,088]	2,214–2,926
S2C3	120,033,900 – 146,313,900	107,323,359 [32,522,230, 227,655,610]	1,320–1,609

Justification. *Need*(s) is arithmetic: pop$(s) \times 1{,}800$ kcal $\times 365$, the 1,800 kcal/day floor being the standard emergency subsistence reference (WFP/Sphere minimum standards). *Supply*(s) applies the U.S. caloric production declines of Xia et al. (2022) at each soot level to a baseline U.S. production of ~ 1.6–1.9×10^9 million kcal/yr (∼13,000–15,000 kcal/cap/day; USDA ERS production data aggregated across food, feed, and fuel uses — the large multiple of dietary need reflecting the fact that most U.S. calories are grown for animals, ethanol, and export), with S2 cells further reduced by E_{infra}'s destruction of fuel, fertilizer, and processing capacity. Supply also accounts for the federal provision floor of $36{,}760{,}000$ million kcal (assembled from CCC inventories, the Bill Emerson Humanitarian Trust, and USDA nutrition-program pipelines).

Calibrating the Tipping Threshold via Historical Cases

We calibrate U^* against eight historical episodes in which an at least quasi-representative government fell amid acute food insecurity. For each case we utilize caloric balance, staple-price shock, and other distributional inputs to derive the same grievance formula used for the United States to recover the implied base-grievance U^* at the moment of collapse: **Caloric Balance at the Moment of Collapse:**

Country	Year	Pop. (M)	Need (10^6 kcal)	Supply (10^6 kcal)	kcal/cap/day	Prov.?	Quantity (10^6 kcal)
France	1789	28	18,396,000	15,330,000	1,500	Y	700,000–1,400,000
France	1848	36.7	24,111,900	23,442,125	1,750	N	—
Russia	1917	130	85,410,000	104,390,000	2,200	Y	3,500,000–7,000,000
Japan	1918	56	36,792,000	42,924,000	2,100	N	—
Ethiopia	1974	24.5	16,096,500	14,969,745	1,674	N	—
Haiti	2008	7.4	4,861,800	5,131,900	1,900	N	—
Sudan	2019	32.2	21,155,400	27,619,550	2,350	Y	700,000–1,000,000
Sri Lanka	2022	16.9	11,103,300	13,879,125	2,250	Y	300,000–700,000

Grievance Computation and Implied U at Collapse:

Country	Year	Gini	e_0 (food share)	π (staple mult.)	Implied U at collapse
France	1789	0.56	0.75	2	0.150 [0.138, 0.161]
France	1848	0.58	0.65	2	0.092
Russia	1917	0.36	0.65	3–5	0.094
Japan	1918	0.50	0.60	2.5	0.120
Ethiopia	1974	0.42	0.70	1.15	0.042
Haiti	2008	0.41	0.65	2	0.053
Sudan	2019	0.34	0.75	1.65–3	0.082 [0.015, 0.102]
Sri Lanka	2022	0.377	0.45	1.95	0.031
Arithmetic mean across cases					0.083

The implied grievance values lie approximately between 0.03 and 0.15, with a cross-case mean of ≈ 0.083, which we adopt as U^*. It is worth noting that several cases (Russia, Japan, Sudan, Sri Lanka) collapsed with aggregate supply exceeding subsistence need, demonstrating that the inadequate distribution of a sufficient quantity of foodstuffs, itself primarily the result of incompetent authorities failing to either support the price mechanism or offer a viable substitute, can often result in political upheaval. Cases from colonial or fully authoritarian famines (Ireland 1845–52, Ukraine 1932–33, Bengal 1943, China 1959–61, North Korea 1994–99) were excluded from this dataset in light of coercion substituting for democratic legitimacy and no upheaval occurring.

Acknowledgments

I would like to thank my project manager, Madeline Berzak, for her extensive guidance and feedback over the course of this project, and for also having been an excellent leader for the duration of my time spent working at XLab thus far. My mentor, Pedro Oliboni, was also kind enough to offer extremely useful feedback several times this summer, each instance of which forced me to truly interrogate several core assumptions and significantly altered the trajectory of this project for the better. Lastly, it was a joy to work alongside all of the fellows constituting XLab's Summer Research Programs. Stimulating conversations with Nico Rose, B. Cullision, Julian Huang, Anaya Mandal, Madeleine Hoffman, Carl Parkin, Patrick Park, and Talia Wilcox have all greatly improved my approach to the project and the process of research more generally.

A Note on AI + LLM Assistance

Claude Opus 5 and Fable 5 were used to enhance the literature, data, and case study search, with the creation of all tables and figures, to produce the results seen in Section 3.1, the formal derivation and proof of the model's key components in Appendix A.

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