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Tokenomics and blockchain fragmentation*

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Abstract

Money is a coordination device underpinned by strong network effects: the more others accept a form of money, the more I wish to adopt it too. The decentralisation agenda of public permissionless blockchains undercuts these network effects and leads to fragmentation of the monetary landscape. Validators who maintain the blockchain need to be rewarded to play their role with the necessary reward increasing in the degree of dependence on other validators' actions to sustain consensus. Since these rewards must ultimately be borne by users through congestion rents, capacity constraints are a feature, not a bug, especially for blockchains with more stringent standards for consensus. New blockchains with less stringent thresholds for consensus enter the market to serve users priced out of incumbent chains. The resulting fragmentation undercuts the very network effects that give money its social value. Stablecoins inherit this fragmentation from the blockchains on which they reside. The analysis has broader implications for the future of the monetary system.

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*The views expressed here are my own and not necessarily those of the BIS.

1 Introduction

Network effects underpin the coordination role of money. The key to its role is the feedback loop between greater acceptance and greater use. The more merchants accept a particular currency, the more consumers wish to hold it; the more consumers hold it, the more merchants wish to accept it. This virtuous circle is the hallmark of a well-functioning monetary system.

Central banks have historically served as the institutional anchor for this coordination. By issuing a uniform currency and standing behind its value, the central bank provides the focal point that enables economic agents to coordinate on a common medium of exchange. The common knowledge of the central bank's commitment is what underpins the self-reinforcing nature of monetary exchange. Just as a common language facilitates communication, a common currency facilitates economic exchange (BIS (2023)).

The promise of blockchain technology was that this coordination function could be replicated without a central authority – that the distributed consensus of validators could substitute for the trust placed in a central bank. In an equilibrium with monetary exchange, holding money is a record of goods sold or services rendered in the past. In this sense, money serves as a record-keeping device. The motto is that "money is memory" (Kocherlakota (1998)). In a centralised system, trusted intermediaries (such as a central bank or a commercial bank) maintain the ledger and have the power to update it. In a decentralised system, this authority is dispersed among *validators* – participants who check and record transactions – and these validators must reach agreement on the true state of the ledger. Truth is whatever is deemed to be so by the consensus of network members.

A blockchain is, at its core, a shared ledger –a list of transactions that is maintained not by a single institution but by a distributed network of validators. Transactions are grouped into "blocks" thatare chained together in sequence, hence the name. A *public permissionless* blockchain is one that anyone can join: there is no gatekeeper deciding who may participate as a validator or as a user.

The de

ning feature of a public permissionless blockchain is its *consensus mechanism* – the set of rules by which validators agree on which transactions are legitimate and in what order they are recorded. Without such a mechanism, validators could disagree about the state of the ledger, and the system could not function as a record-keeping device. The original consensus mechanism introduced by Bitcoin was *proof of work* (PoW), where validators (called "miners" in this context) compete to solve a computationally intensive cryptographic puzzle. The winner earns the right to add the next block of transactions and receives a reward – newly minted tokens plus fees paid by users. The more recent and now more widely adopted mechanism is *proof of stake* (PoS), where validators pledge a quantity of the blockchain's native token as collateral (their "stake"). Validators are selected to propose and verify blocks in proportion to their stake, and misbehaviour is punished by "slashing" – the confiscation of staked tokens.

Ethereum's transition from PoW to PoS in September 2022 (the "Merge") marked a turning point. It reduced the blockchain's energy consumption sharply while shifting the economic foundations of validator incentives from hardware investment to capital lock-up. But the core coordination problem remained: validators must still be sufficiently rewarded to contribute to the governance of the blockchain. The rewards must compensate validators not only for the direct costs of running infrastructure but also for the risk that the group of validators fails to coordinate.

This coordination problem manifests concretely in *gas fees* – the transaction fees that users pay to have their transactions processed and recorded on the blockchain. The term "gas" is an apt metaphor: just as a car needs fuel to run, every operation on a blockchain requires computational effort by validators, and users must pay for that effort. When many users want to transact at the same time, they bid against each other for limited block space, and fees spike – much as taxi fares surge during rush hour. Figure 1 shows how Ethereum gas fees exhibited sharp spikes during periods of network congestion, such as during surges in decentralised finance (DeFi) activity or spikes in the minting of non-fungible tokens (NFTs). These spikes are not merely a reflection of excess demand; they are the mechanism through which the blockchain extracts the rents needed to sustain validator coordination.

The relationship between gas fees and validator incentives reveals a fundamental tension. When demand for block space is high, fees rise and validators are well compensated. But high fees deter users, especially those making small or routine transactions. These users are

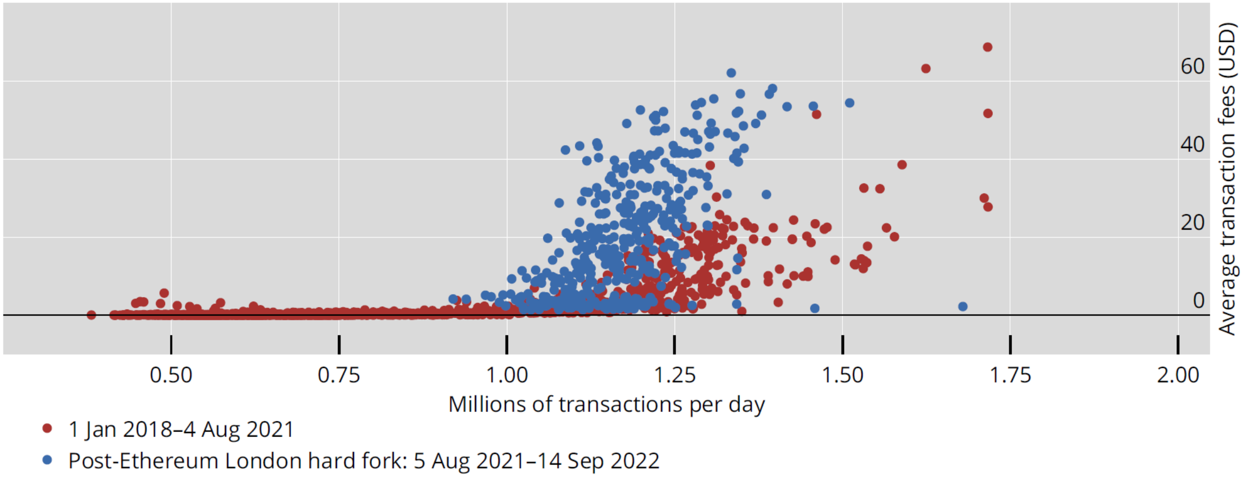

Figure 1: **Ethereum gas fees.** The figure shows the evolution of average gas fees on the Ethereum network. Spikes in gas fees coincide with periods of peak network activity, such as surges in DeFi activity and NFT minting. These fee spikes reflect the congestion rents that are necessary to sustain the incentives of validators who contribute to governance. The high-fee episodes are also the periods that saw the greatest outflow of users to competing blockchains such as Solana and BNB Chain. Sources: Etherscan; BIS calculations.

the first to migrate to competing blockchains that offer lower fees – blockchains that can offer lower fees precisely because they have lower coordination thresholds (and hence less security). The users who remain on the more secure blockchain are those with the highest willingness to pay: institutions, large DeFi protocols, and transactions where security and censorship resistance are paramount. This sorting of users across blockchains is the essence of fragmentation.

Figure 2 illustrates the crucial distinction. The new user in the left-hand panel chooses the more crowded venue due to the network effects: greater use leads to greater acceptance, which reinforces further use. The right-hand panel shows how capacity constraints on one blockchain push users to competing platforms, so that the network effects that underpin money are undermined. Instead of convergence toward a single medium of exchange, the result is fragmentation.

The fragmentation of the blockchain universe arises from the fact that capacity constraints are necessary to incentivise validators to perform their governance tasks, making the consensus mechanism self-sustaining. When Ethereum's gas fees spiked during periods of

Figure 2: **Network effects and strategic substitutability in money.** The left-hand panel illustrates the virtuous circle of network effects: greater acceptance leads to greater use, which reinforces acceptance. The right-hand panel illustrates strategic substitutability: when capacity constraints on one blockchain push users to competing platforms, the network effects that underpin money are undermined. Instead of convergence toward a single medium of exchange, the result is fragmentation.

heavy use – peaking at levels that made even routine transactions prohibitively expensive for many users – the response was the emergence of alternative blockchains. Solana attracted users with low fees and high throughput. Tron became the workhorse for cross-border stablecoin transfers in emerging markets. BNB Chain, Avalanche, and dozens more carved out their own niches. By 2025, Solana, Tron, and Ethereum were each generating fee revenue of broadly comparable magnitude,[1] reflecting a landscape in which no single chain dominates all use cases. This fragmentation is not an accident or market failure; it is the consequence of the token economics ("tokenomics") of decentralised consensus.

Congestion in decentralised ledgers undercuts the network effects of money. When transaction fees become too high on one blockchain, users migrate to alternatives. New blockchains emerge to cater to these users, and the user base splinters across multiple platforms. Rather than the virtuous circle of greater acceptance and greater use, there is a fragmentation of the monetary landscape.

The blockchain universe has displayed precisely such fragmentation. Figure 3 shows the evolution of the *layer 1* blockchain landscape. A layer 1 (or "L1") blockchain is a base-level network that processes and finalises transactions on its own ledger – Ethereum, Solana, and Tron are all layer 1 chains. The term distinguishes these foundational networks from *layer 2*

[1] Annualised fee revenue for each chain was in the range of $500–600 million by late 2025. Source: Token Terminal (`https://tokenterminal.com`).

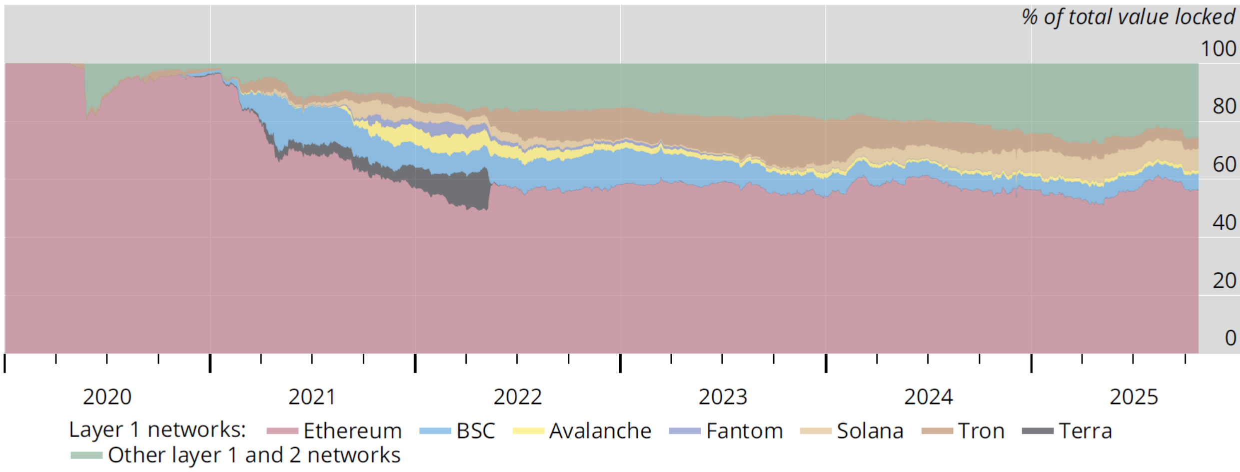

Figure 3: **Layer 1 blockchain fragmentation.** The figure illustrates the proliferation of layer 1 blockchains and the dispersion of activity across platforms. Rather than coalescing around a single dominant platform, the ecosystem has become increasingly fragmented, with new blockchains capturing users who are deterred by high fees on incumbent chains. Sources: CoinMetrics; DeFiLlama; BIS calculations.

("L2") blockchains, which are secondary networks built on top of an L1 chain to handle transactions more cheaply, periodically settling back to the base layer for security. (Layer 2 solutions are discussed further in Section 3.) Ethereum, once the dominant platform for decentralised applications, has seen its share of activity eroded by a host of competitors. Solana has attracted users seeking low-cost, high-speed transactions. Tron has become the backbone for stablecoin transfers in emerging markets, particularly in Asia, the Middle East, and Africa. BNB Chain, Avalanche, Sui, Base, and many others have each carved out their own niches. At the time of writing, dozens of blockchain ecosystems had attracted meaningful activity, with the bulk of transactions concentrated on the largest chains.[2]

The fragmentation is also evident in the stablecoin landscape. Rather than converging on a single platform, stablecoin activity is scattered across many chains (Figure 4). As of late 2025, Ethereum held the majority of total stablecoin supply but was facing competition from Tron and Solana, each of which had attracted tens of billions of dollars in stablecoin balances.[3] Each chain serves different geographies and use cases: Ethereum for institutional

[2]DeFiLlama tracked over 60 active blockchains as of late 2025. See `https://defillama.com/chains`.

[3]DeFiLlama stablecoin dashboard, `https://defillama.com/stablecoins`. As of December 2025, Ethereum held roughly 55 percent of aggregate stablecoin supply, Tron approximately $79 billion, and Solana

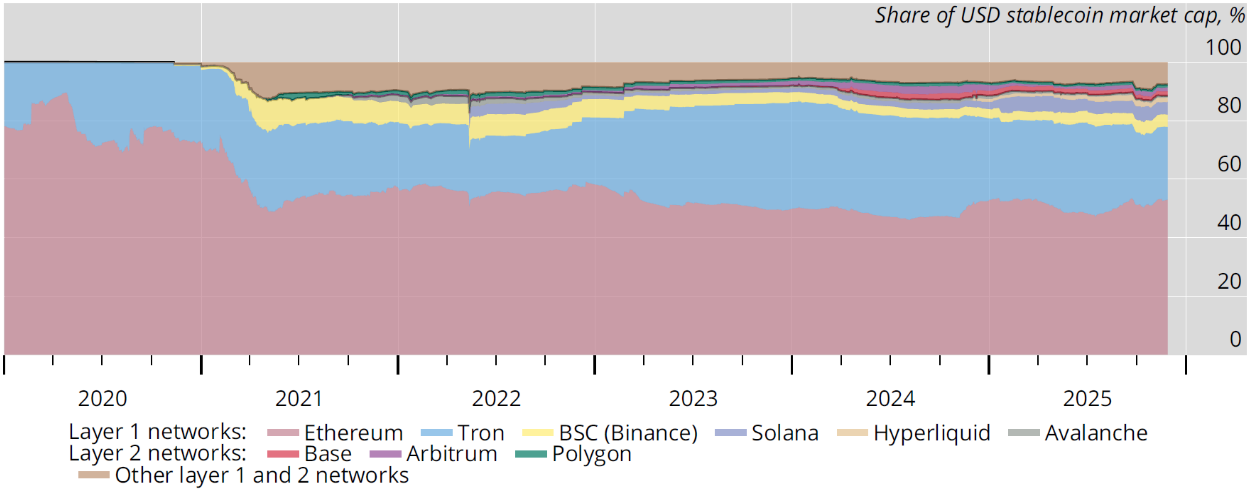

Figure 4: **Stablecoin fragmentation across blockchains.** The figure shows the distribution of stablecoin supply and activity across multiple blockchains. Ethereum remains the largest single platform, but a growing share of stablecoin activity has migrated to competing chains such as Tron and Solana. The fragmentation of stablecoins across chains undermines the fungibility and interoperability that a payment instrument requires. Sources: CoinMetrics; DeFiLlama; BIS calculations.

settlement, Tron for low-cost remittances, Solana for retail payments and DeFi activity.

Crucially, stablecoins on different blockchains are not interoperable (Figure 5). A USDC token on Ethereum is not the same as a USDC token on Solana – they exist on separate ledgers that have no native way of communicating with each other. Transferring between chains requires the use of *bridges*: specialised software protocols that lock tokens on one chain and issue equivalent tokens on another. These bridges introduce additional risks, including vulnerabilities in the smart contract code – bridge exploits have accounted for billions of dollars in cumulative losses[4] – and they impose costs and delays that undermine the seamless transferability that is the hallmark of money. The result is a landscape in which stablecoins from the same issuer exist in multiple, non-fungible forms across different blockchains, fragmenting liquidity and undercutting the network effects that should be the strength of a widely adopted payment instrument.

The economics of validator incentives, as developed below, provides an explanation of such

over $16 billion.

[4] Chainalysis estimated cumulative bridge hack losses at over $2.5 billion between 2021 and 2024. See Chainalysis, *Crypto Crime Report* (2024).

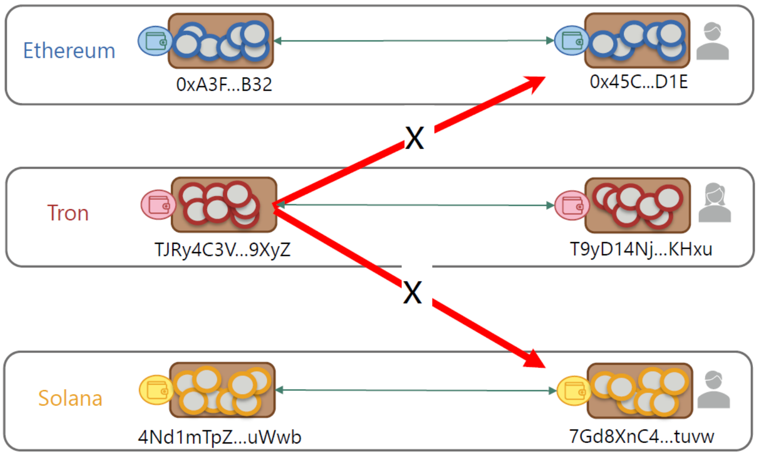

Figure 5: **Stablecoins are not interoperable across blockchains.** The figure illustrates how the same stablecoin (e.g. USDC) exists in separate, non-fungible forms on different blockchains. Transferring stablecoins across chains requires the use of bridges, which introduce risks, costs, and delays. This lack of interoperability fragments liquidity and undermines the network effects of a single payment instrument. Sources: BIS.

fragmentation. Decentralised infrastructures come with a built-in tendency toward fragmentation that works against the very network effects that give money its social value. The fragmentation argument is the flipside of blockchain's "scalability trilemma," as described by Vitalik Buterin (Buterin (2021)), who posed the problem as the impossibility of attaining, simultaneously, a ledger that is decentralised, secure, and scalable. The contribution of this paper is to provide a formal economic mechanism that underpins this trilemma and to draw out its implications for the monetary system. The theoretical framework draws on the global games literature (Morris and Shin (1998, 2003)), and the formal analysis extends the approach in Auer, Monnet, and Shin (2025).

1.1 Related literature

The literature on the network effects of money has deep roots. Menger (1892) first articulated the idea that money emerges as the most marketable commodity through a self-reinforcing process: the more widely a commodity is accepted, the more others wish to hold it, until one commodity emerges as the dominant medium of exchange. Jevons (1875) identified the "double coincidence of wants" as the core friction that money resolves. These classical insights were formalised by Kiyotaki and Wright (1989, 1993), whose search-theoretic models show how money can arise as a coordination equilibrium among agents who would otherwise struggle to trade. A central lesson of these models is that the monetary equilibrium exhibits powerful *strategic complementarities*: the more agents accept a particular token, the greater each agent's incentive to accept it. Matsuyama (1993) extends this logic to show that the welfare gains from monetary exchange are increasing in the breadth of the network, so that fragmentation – the coexistence of multiple, weakly connected monetary networks – is inherently costly.

The coordination perspective on money connects to a broader literature on increasing returns and network effects in the adoption of standards and technologies (Arthur (1989), Katz and Shapiro (1985)). Just as the value of a telephone network increases with the number of subscribers, the value of a currency increases with the number of users. But unlike a telephone network, where interoperability standards can link competing platforms, the interoperability of competing monetary networks is much harder to achieve – especially when the networks are built on incompatible decentralised ledgers.

The economics of blockchain consensus has attracted growing attention. Huberman, Leshno, and Moallemi (2021) provide an early economic analysis of transaction fees in Bitcoin. Easley, O'Hara, and Basu (2019) study the evolution of Bitcoin transaction fees and the implications for market design. Pagnotta (2022) links Bitcoin prices to the security properties of the blockchain. Cong, He, and Li (2021) analyse the tension between decentralised mining and the centralisation of mining pools – a tension that foreshadows the coordination problem studied here. On stablecoins, Gorton and Zhang (2023) draw a parallel with the "wildcat banking" era when privately issued banknotes proliferated without a uniform currency, and Makarov and Schoar (2022) provide an overview of decentralised finance and its structural challenges.

The broader literature on money and institutional design provides further conceptual foundations. Kocherlakota (1998) establishes the formal equivalence between money and memory. Brunnermeier and Niepelt (2019) analyse the conditions under which private and public money are equivalent. On the design of distributed ledgers, Townsend (2020) provides a comprehensive treatment, while Catalini and Gans (2020) discuss the simple economics of blockchain. Chiu and Koeppl (2019) study blockchain-based settlement.

The global games methodology that underpins the theoretical analysis originates with Carlsson and van Damme (1993) and was developed by Morris and Shin (1998, 2003). The approach has been applied to bank runs (Goldstein and Pauzner (2005), Rochet and Vives (2004)) and to debt markets (Morris and Shin (2004)). Auer, Monnet, and Shin (2021, 2025) apply the global games framework to the governance of distributed ledgers, providing the direct antecedent for the present paper.

The rest of this paper is organised as follows. Section 2 develops the theory. It first describes the variety of consensus mechanisms across blockchains, then sets up the formal global game model and derives the key results on validator rewards and blockchain capacity. Section 3 draws out five key lessons from the analysis. Section 4 offers concluding remarks.

2 Elements of a theory

For decentralisation to work, individual validators have to be incentivised to play their part in the consensus mechanism. The consensus mechanisms used by public permissionless blockchains vary in terms of their precise rules.

2.1 Consensus mechanisms

Table 1 lists the consensus mechanisms of five prominent blockchains. Although the mechanisms differ in their details, they share common features that can be distilled into a general framework.

Bitcoin's proof of work mechanism (Nakamoto (2008)) requires miners to expend computational resources to solve a cryptographic puzzle. The high energy cost serves as a commitment device that raises the cost of subverting the ledger. However, this comes at the price of low throughput and high energy consumption, which limits Bitcoin's capacity as a payment system (Huberman, Leshno, and Moallemi (2021)). Ethereum's proof of stake

Table 1: **Consensus mechanisms of major blockchains.** The table lists the consensus mechanisms of five prominent blockchains and how each mechanism works. The details differ, but all mechanisms share the common feature of requiring coordination among validators to maintain the integrity of the ledger.

Chain	Consensus mechanism	How it works
Bitcoin	Proof of work	Miners solve hash puzzles
Ethereum	Proof of stake	Validators stake ETH; slashing punishes misbehaviour
BNB Chain	Proof of staked authority	Validators elected by BNB stake; rotate blocks
Solana	Proof of history/BFT voting	Stake-weighted leader proposes; validators vote
Tron	Delegated proof of stake	TRX holders elect 27 super representatives

replaces energy expenditure with capital lock-up, dramatically reducing environmental costs while retaining the economic logic of incentive compatibility. BNB Smart Chain and Tron both adopt variants of delegated proof of stake, in which a smaller set of validators is elected by token holders. This reduces the coordination burden – fewer validators need to agree – but at the cost of greater centralisation. Solana's proof of history supplements its BFT voting process with a cryptographic clock that orders transactions before consensus is reached, enabling high throughput with sub-second finality.

The key observation across all these mechanisms is that there is a trade-off between the stringency of the coordination requirement and the cost of achieving consensus. Mechanisms that require broader participation (more validators, higher consensus thresholds) provide greater security and censorship resistance but require higher rewards for validators to maintain incentives (as explained in more detail below). Mechanisms with narrower participation (fewer elected validators, lower thresholds) can offer lower fees and higher throughput, but at the cost of reduced decentralisation. This trade-off motivates the general framework that follows.

All these mechanisms share the common feature that they must be self-sustaining in the sense that when other validators follow the rules as prescribed by the consensus mechanism, it is in the interests of a particular validator also to follow the rules. In the language of game theory, the protocol described in the consensus mechanism must constitute an equilibrium of a game.

For the main theoretical discussion, it is useful to work with a general approach to consensus mechanisms so that we can extract the key economic lessons.

For this purpose we work with a general coordination problem with the following features. Suppose there is a large number of validators, where each validator has a binary choice between contributing to the governance of the blockchain (bearing a small cost), or opting out and free-riding on the other validators. Although contributing to governance entails a cost, provided that enough of the other validators contribute to governance, an individual validator prefers to contribute. The crucial element is what determines "enough." A unanimity rule would be a very stringent criterion for what constitutes "enough." A less stringent rule would be a supermajority where the threshold for successful coordination is lower – say, a two-thirds supermajority.

The more stringent is the threshold, the more secure is the blockchain. However, the greater security comes with a cost. The higher threshold for successful coordination raises the stakes for the individual validator who is weighing up the benefits and costs. Incurring the cost of governance contribution needs to be weighed against the fallout from a failure of the validator group to coordinate on the good equilibrium.

For this reason, more secure blockchains with a higher threshold for successful coordination have to provide higher rewards to the validators to compensate them for the risks that arise from potential miscoordination. The higher the threshold for successful coordination, the higher must be the reward. In the limiting case where unanimity is required to update the ledger, it turns out that the required rewards to the validators tend to infinity. In other words, a blockchain that needs unanimity among self-interested validators cannot function with finite rewards.

The upshot is that the viability of a blockchain depends on the rewards that can be paid to the validators. The more stringent is the required supermajority to achieve consensus, the higher must be the reward. Since users of the blockchain must ultimately pay for the rewards that go to the validators, the more the users are willing to pay for the privilege of using the blockchain, the greater is the stringency of the supermajority threshold that determines successful coordination of governance. However, the user base of a particular blockchain is limited by the willingness to pay of its users. The blockchain extracts the surplus from the group of users. The capacity of the blockchain is set from the outset so as to ensure that a sufficiently high stream of rents accrues to the participating validators. In this sense, congestion of the blockchain is a feature, not a bug. The congestion is necessary to ensure that users pay sufficiently high gas fees to reward the validators.

2.2 Global game

We proceed to formalise the stylised consensus mechanism introduced above. There is a continuum of validators indexed by the unit interval $[0,1]$. Each validator chooses between two actions - either to contribute to governance, or to opt out. Contributing to governance entails a cost, and these costs vary across validators. For validator $i \in [0,1]$, the cost of contributing to governance is $c_i > 0$.

The blockchain functions well provided that enough validators work to fulfil governance duties, where "enough" is defined in terms of a threshold $\hat{\kappa}$. Provided that proportion $\hat{\kappa}$ or more of the validators contribute to governance, the blockchain functions as intended. A high $\hat{\kappa}$ corresponds to a more stringent condition for successful achievement of consensus on the blockchain. The higher is $\hat{\kappa}$, the greater is the proportion of validators who need to contribute in order to reach consensus. The higher is the threshold $\hat{\kappa}$, the more the blockchain becomes "censorship resistant." If the blockchain functions well, validators who contribute to governance earn a reward $\rho > 0$. This reward comes from the fees paid by users and from any additional benefits (such as miner extractable value, or MEV) that come from the ability to determine the sequence of transactions. A validator who opts out of contributing governance receives a payoff of zero regardless of what others do.

There are two special cases of note: $\hat{\kappa} = 1$ (unanimity, corresponding to full decentralisation where every validator must participate for the blockchain to function) and $\hat{\kappa} = 0$ which corresponds to full centralisation, where one validator has authority to update the ledger. The unanimity case represents the most secure but also the most demanding coordination requirement. The centralised case corresponds to a traditional trusted intermediary.

Formally, the payoff to contributing to governance depends on whether enough of the other validators also contribute to governance. Let κ denote the proportion of validators who contribute. Then the payoff to contributing to governance is:

$$\begin{cases} \rho - c_i & \text{if } \kappa \geq \hat{\kappa} \\ -c_i & \text{if } \kappa < \hat{\kappa} \end{cases} \tag{1}$$

Assume that the cost c_i is tightly distributed around a common cost c such that:

$$c_i = c + \eta_i \tag{2}$$

and η_i is uniformly, independently, and identically distributed over the interval $[-\varepsilon, \varepsilon]$.

For simplicity of argument, assume that the common component c is chosen from a uniform density, so that a validator with cost c_i believes that the common cost component c has a uniform posterior density over the interval $[c_i - \varepsilon, c_i + \varepsilon]$.[5]

A *strategy* for a validator is a mapping from the realised cost c_i to an action - to contribute to governance or to opt out. The validators face a coordination problem. An individual validator wants to fulfil governance duties provided that a critical mass of other validators do so. An *equilibrium* of the game is a set of strategies where the action prescribed by validator i's strategy given cost c_i maximises the expected payoff of that validator given the strategies followed by all other validators.

2.3 Solution

The main result is that there is a unique, dominance-solvable equilibrium of the game. Uniqueness follows from the iterated deletion of strictly dominated strategies, exploiting the facts that the payoff to contributing is decreasing in own cost c_i and increasing in the proportion of other contributors κ. In this equilibrium, each validator i works to fulfil governance duties if and only if c_i is below a critical level c^* where

[5] This assumption is not necessary for the main result reported below for the limiting case when $\varepsilon \to 0$, but it allows a simpler argument.

$$c^* = \rho(1 - \hat{\kappa}) \tag{3}$$

This result follows from techniques developed in the global games literature (Morris and Shin (1998, 2003)).

The argument proceeds in three steps.

Step 1. suppose that validators are confined to using "switching strategies" around a common cost threshold c^*, where they contribute to governance if their cost is below this threshold and opt out otherwise. In this case, a marginal validator i who has $c_i = c^*$ has so-called "Laplacian beliefs" over κ, which is to say that the marginal validator has *uniform* beliefs over the proportion κ of validators who contribute to governance.

The formal argument is given in the Appendix. Intuitively, even though the marginal validator may have very precise information about the common cost c, the validator faces irreducible uncertainty about how many other validators will choose to contribute. It is this strategic uncertainty – uncertainty about others' actions – that is the central feature of the coordination problem.

Step 2. The marginal validator with cost $c_i = c^*$ is indifferent between contributing and opting out. This indifference condition ties down c^* to be exactly $\rho(1 - \hat{\kappa})$. Figure 6 gives the graphical argument. The marginal validator who contributes to governance earns the reward ρ if the supermajority threshold $\hat{\kappa}$ is met (that is, provided $\kappa \geq \hat{\kappa}$). By contributing to governance, the validator incurs the cost c^*. The marginal validator who is indifferent between contributing and opting out must satisfy the condition that the expected payoff from contributing equals the expected payoff from opting out. In Figure 6, the rectangle A represents the expected loss (cost c^* incurred over the region where $\kappa < \hat{\kappa}$) and rectangle B represents the expected gain (net reward $\rho - c^*$ earned over the region where $\kappa \geq \hat{\kappa}$). At the indifference point, $A = B$. Setting these areas equal yields the condition that the cost c^* at the switching point satisfies $c^* \cdot \hat{\kappa} = (\rho - c^*)(1 - \hat{\kappa})$, which simplifies to equation (3): $c^* = \rho(1 - \hat{\kappa})$.

Additionally, when all other validators follow the same switching strategy around c^*, an individual validator strictly prefers to contribute if $c_i < c^*$, and strictly prefers to opt out

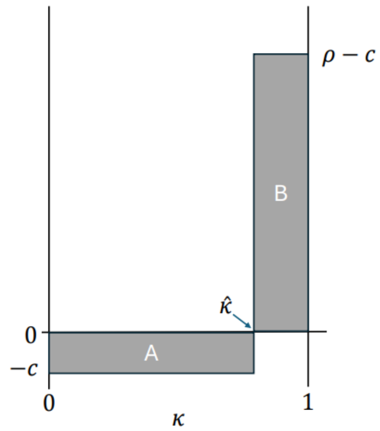

Figure 6: The payoff to contributing to governance is $\rho - c$ if enough validators contribute to govenrance (ie, when $\kappa \geq \hat{\kappa}$) but is $-c$ if not enough validators contribute. The payoff to opting out is zero. The validator with Lapacian beliefs is indifferent when the area of rectangle A is equal to rectangle B.

if $c_i > c^*$. Thus, the set of strategy profiles where all validators use the switching strategy around c^* is an equilibrium of the game. Since there is only one such switching strategy, step 2 proves that there is a unique equilibrium in switching strategies.

Step 3. The final step of the argument is to show that the equilibrium in switching strategies identified in Step 2 is, in fact, dominance solvable and can thus be obtained through the iterated deletion of strictly dominated strategies. This final step shows that the equilibrium identified above is not only the unique equilibrium when validators are confined to using switching strategies, but it is the unique equilibrium when the possible strategies is unconstrained. In that sense, the solution we obtain is the only solution of the game. The details of Step 3 are in Morris and Shin (2003).

2.4 Characterising the equilibrium

In the limit as $\varepsilon \to 0$, all validators share the common cost c, so the coordination equilibrium is sustained if and only if the common cost falls below the switching point: $c \leq c^* = \rho(1-\hat{\kappa})$. Rearranging this condition, the reward ρ has to be sufficiently large so that:

$$c\hat{\kappa} \leq (1-\hat{\kappa})(\rho - c) = (1-\hat{\kappa})\,\rho - (1-\hat{\kappa})\,c \tag{4}$$

Given supermajority threshold $\hat{\kappa}$, validation is therefore successful if $c \leq (1-\hat{\kappa})\,\rho$. In other words, validation is successful if the reward ρ is sufficiently high so that:

$$\rho \geq \frac{c}{1-\hat{\kappa}} \tag{5}$$

Note that the required reward ρ explodes as $\hat{\kappa} \to 1$. This is the central result of the paper: the more decentralised the blockchain (the higher the supermajority threshold), the higher must be the rents that accrue to validators. In the limiting case of unanimity ($\hat{\kappa} = 1$), no finite reward can sustain the coordination equilibrium.

We can state the solution of the game more formally as follows.

Proposition 1 *For a blockchain with supermajority threshold $\hat{\kappa}$ and common validator cost c, the minimum reward ρ^* that sustains the blockchain is $\rho^* = c/(1-\hat{\kappa})$. The required reward is strictly increasing in $\hat{\kappa}$ and tends to infinity as $\hat{\kappa} \to 1$. Moreover, this equilibrium is the unique, dominance-solvable equilibrium of the game.*

Proof. The three step derivation above establishes that the switching point satisfies $c^* = \rho(1-\hat{\kappa})$, from which the minimum reward follows by rearrangement. Strict monotonicity in $\hat{\kappa}$ follows from the fact that $\rho(1-\hat{\kappa})$ is increasing in $\hat{\kappa}$. Finally, note that $\rho^* \to \infty$ as $\hat{\kappa} \to 1$. Uniqueness follows from dominance solvability (Morris and Shin (2003)). ■

In the limit as $\varepsilon \to 0$, all validators have the same cost, but the density of κ is uniform at the switching point (Morris and Shin (1998, 2003)). The parameter ε governs the degree of heterogeneity among validators. As $\varepsilon \to 0$, all validators become nearly identical, but – and this is the key insight from the global games literature – the *strategic uncertainty* over the actions of other validators does not vanish.

The uniqueness of the equilibrium is what gives the result its analytical power: there is no ambiguity about which equilibrium will be selected. The global games approach resolves the equilibrium selection problem that plagues coordination games with common knowledge.

It is instructive to consider the two limiting cases. When $\hat{\kappa} = 0$ (full centralisation), the minimum reward is $\rho^* = c$: validators need only be compensated for their direct costs, with no coordination premium. When $\hat{\kappa} = 1$ (unanimity), the minimum reward tends to infinity.

The pure *coordination premium* is given by:

$$\rho^* - c = \frac{c\hat{\kappa}}{1-\hat{\kappa}} \tag{6}$$

This expression represents the additional compensation that goes to validators beyond the cost c that they expend. This is the additional compensation for bearing the risk that others may fail to contribute. It is this coordination premium that drives the fragmentation result.

2.5 Blockchain capacity

The result in equation (5) has direct implications for the capacity of the blockchain. The rewards to validators must ultimately be borne by the users of the blockchain through the fees they pay for transactions. If users have heterogeneous willingness to pay for block space, the blockchain's capacity is determined by the number of users who are willing to pay the equilibrium fee.

Suppose there is a downward sloping demand function $D(\rho)$ which gives the size of the population of users who use the blockchain as a function of the rent ρ. Then, given $\hat{\kappa}$, the capacity of the blockchain is given by

$$D(\rho^*) \tag{7}$$

where

$$\rho^* = \frac{c}{1-\hat{\kappa}} \tag{8}$$

Hence, the capacity of the blockchain is given by

$$D\left(\frac{c}{1-\hat{\kappa}}\right) \tag{9}$$

Since D is downward sloping, the capacity is decreasing as $\hat{\kappa}$ increases. This result formalises the scalability trilemma: a blockchain cannot simultaneously be maximally decentralised ($\hat{\kappa}$ close to 1), secure (which also requires high $\hat{\kappa}$), and scalable (which requires low ρ and hence low $\hat{\kappa}$).

The users who are excluded from the blockchain – those whose willingness to pay falls short of ρ^* – are the natural constituency for a new, less decentralised blockchain with a lower supermajority threshold $\hat{\kappa}' < \hat{\kappa}$. This new blockchain requires lower rewards $\rho' = c/(1-\hat{\kappa}')$ and can therefore offer lower fees, attracting the marginal users. But this new blockchain is less secure: its lower supermajority threshold makes it easier for a coordinated attack to succeed. The trade-off between security and scalability is inescapable.

This mechanism explains the empirical landscape: Ethereum, with its large validator set and high degree of decentralisation, charges higher fees and serves institutional users and large DeFi protocols. Solana, with its higher throughput and lower decentralisation, attracts retail users and high-frequency applications. Tron, optimised for simple value transfers, handles the bulk of stablecoin remittances. Each chain occupies a niche in the security–scalability frontier, and the ecosystem as a whole fragments rather than consolidates.

The framework extends naturally to layer 2 (L2) solutions. An L2 chain inherits the security of its base layer for final settlement but runs its own coordination game among sequencers or validators, with its own threshold $\hat{\kappa}^{L2}$ and associated reward ρ^{L2}. Since L2s typically employ a smaller, more centralised set of sequencers, they can offer lower fees. However, each L2 constitutes a separate coordination equilibrium with its own user base and liquidity pool. The fragmentation result therefore applies across layers as well as across chains: users who are priced out of the base layer migrate to L2s, but these L2s do not share a common liquidity pool or settlement mechanism, replicating the fragmentation problem at a different level of the stack.

3 Lessons

The theoretical framework developed above carries several important lessons.

Lesson 1: Decentralisation has an irreducible cost

The central insight of the model is that decentralisation comes with a cost. The coordination problem among validators requires that they be compensated not merely for the direct costs of running nodes, but for the strategic risk that the group may fail to coordinate. This compensation takes the form of rents extracted from users. The more decentralised the system (with higher thresholds for governance), the higher these rents must be. This is a structural feature of any system that relies on decentralised consensus among self-interested agents, and it cannot be engineered away through better technology or clever mechanism design.

This insight has a more general counterpart. Whenever a system relies on the voluntary participation of agents who face a coordination problem, there is an efficiency loss relative to a system where a trusted authority can ensure a good outcome. The coordination premium $\rho^* - c = c\hat{\kappa}/(1-\hat{\kappa})$ quantifies this efficiency loss: it is zero when coordination is trivial ($\hat{\kappa} = 0$) and infinite when unanimity is required ($\hat{\kappa} = 1$). In the context of the monetary system, this premium manifests as the congestion costs and fragmentation that characterise the crypto ecosystem.

The irreducibility of this cost deserves emphasis. It is tempting to believe that advances in computer science – faster consensus algorithms, more efficient data structures, hardware acceleration – can eliminate the coordination premium. But the premium is not a computational bottleneck; it is a *strategic* one. Advances in technology can reduce the direct cost c of running a validator node, but it cannot eliminate the strategic uncertainty that drives the coordination premium $\rho^* - c = c\hat{\kappa}/(1-\hat{\kappa})$. The cost of decentralisation is rooted in the incentives of individual agents, not in the limitations of machines.

Lesson 2: Congestion is a feature, not a bug

The observation that blockchain congestion is a feature rather than a bug deserves emphasis, because it overturns the common narrative that congestion is merely a technical limitation to be overcome by better engineering. From the standpoint of tokenomics, the blockchain *needs* to be congested. Without congestion, fees would fall to levels that cannot sustain the validator coordination equilibrium. The capacity of the blockchain is not something to be maximised; it is something to be calibrated to the level that generates sufficient rents for validators.

Consider the analogy of a toll road. A highway authority could build enough lanes to eliminate congestion, but if it relies on toll revenue to finance the road, some degree of congestion is necessary to keep tolls high enough to cover costs. The blockchain faces the same logic, with the additional twist that the "road" must also pay for its own governance. If fees fall too low, validators withdraw, the consensus mechanism weakens, and the security of the entire ledger is compromised. The congestion that frustrates users is the very mechanism that keeps the system viable.

This explains why efforts to scale blockchains – through layer 2 solutions, sharding, or other techniques – have not eliminated congestion but have instead led to the fragmentation of activity across multiple layers and chains. Ethereum's layer 2 ecosystem (Arbitrum, Optimism, Base, and others) has succeeded in lowering fees for individual users, but at the cost of further fragmenting liquidity and creating new coordination challenges across layers. Indeed, the proliferation of L2 chains has created a new version of the same problem: each L2 is itself a separate platform with its own liquidity pool, its own user base, and its own coordination dynamics. Users on two different L2 platforms cannot seamlessly interact with each other just as Ethereum users cannot seamlessly interact with Solana users. The fragmentation has merely shifted from the L1 level to the L2 level.

Lesson 3: Stablecoins inherit the fragmentation of the blockchain rails

Money derives its usefulness from network effects. The social value of a monetary system increases with the number of people who use it. Fragmentation – the splitting of users across multiple, non-interoperable platforms – directly undermines these network effects. Stablecoins inherit the fragmentation of the blockchains on which they reside. A USDC token on Ethereum is *not* identical to a USDC token on Solana, even though they are minted by the same issuer. They cannot be directly exchanged; transferring between them requires a bridge, which introduces delay, cost, and risk of hacks. The same nominal instrument exists in multiple non-fungible forms, fragmenting liquidity and partitioning the user base.

The fragmentation is not merely inconvenient – it is structurally incompatible with the network effects that give money its social value. Recall the insight from Kiyotaki and Wright (1989): money is valuable because it is universally accepted. When the "same" stablecoin exists in half a dozen non-interoperable forms on different chains, the effective network is not the total number of stablecoin holders worldwide but the number of holders on a particular chain.

The policy discussion around stablecoins has revolved around the questions of backing assets, redemption terms and disclosures. But good regulation does not address the fragmentation problem. Rules on backing or redemption terms constrain the stablecoin issuer but do not alter $\hat{\kappa}$ or ρ on any blockchain. The question of which rails carry the stablecoin is left entirely to market forces, and it is the economics of the rails, as formalised above, that drives fragmentation.

Lesson 4: The singleness of money requires a trust anchor

The analysis brings into sharp relief the role of central banks in maintaining the *singleness of money* – the principle that a payment always goes through at par whatever form it takes. The singleness of money is not a technological feature; it is an institutional one. It rests on the settlement function of the central bank.

This institutional architecture is easy to take for granted precisely because it works so well. When a consumer pays a merchant using a debit card, the payment involves a transfer from the consumer's bank to the merchant's bank. These are different institutions with different balance sheets, yet the transaction settles seamlessly because both banks hold accounts at the central bank, and the central bank guarantees that a dollar in one bank is worth exactly a dollar in the other. The central bank achieves this through its willingness to convert commercial bank deposits into central bank reserves on demand.

In a decentralised system, there is no entity that can guarantee the par convertibility of stablecoins on different chains. The contrast with the traditional monetary system is instructive. In the traditional system, the network effects of money are *reinforced* by the institutional architecture: the central bank's settlement function ensures that all forms of dollar-denominated money are perfect substitutes, maximising the breadth of the network. In the decentralised system, the infrastructure *undermines* network effects: the fragmentation of blockchains ensures that nominally identical stablecoins are imperfect substitutes, splintering the network. The coordination gains from universal acceptance are dissipated.

Any well-functioning monetary system requires a trust anchor – an institution whose commitment to maintain par conversion is credible and whose balance sheet is large enough to absorb shocks. The central bank has traditionally played this role, and the analysis suggests that no purely decentralised arrangement can replicate this function. The reason is rooted in the coordination economics developed above: the more one insists on decentralisation, the higher the cost and the greater the fragmentation. A trust anchor is not a concession to imperfect technology; it is a structural requirement of any monetary system that aspires to universal acceptance.

Lesson 5: The design of the monetary infrastructure matters

If the future monetary system involves stablecoins and tokenised assets alongside traditional forms of money, the crucial question is how these different components connect. The points of contact between the crypto world and the conventional monetary system – the on-ramps and off-ramps, the regulatory perimeter, the settlement mechanisms – will determine whether the system achieves the network effects of a unified monetary framework or falls into the trap of fragmentation.

The key insight from the analysis is that fragmentation is not primarily a problem of *instruments* (stablecoins, deposits, banknotes) but a problem of *infrastructure* (the rails on which those instruments travel). A well-designed infrastructure can make different instruments interoperable, thereby preserving network effects; a poorly designed infrastructure fragments them. The traditional monetary system achieves interoperability through the central bank's settlement function. The question for the future is whether digital infrastructure can achieve comparable interoperability.

One approach is to build on the concept of a "unified ledger" (BIS (2023)), which envisages a common platform where tokenised central bank money, tokenised commercial bank deposits, and other digital assets coexist on a programmable platform. Such a platform, anchored by the central bank, could harness the benefits of programmability and tokenisation while preserving the singleness of money. The unified ledger approach addresses the fragmentation problem by construction: the coordination problem among validators is replaced by the institutional commitment of the central bank. The analysis of this paper identifies the key criterion for a successful incorporation of stablecoins into the monetary system: any viable solution must overcome the coordination costs of decentralised consensus without sacrificing the network effects that give money its social value.

The broader implication is that the design of the monetary system cannot be left entirely to market forces. The tendency toward fragmentation in decentralised systems is a structural feature, not a transient phenomenon. Policy choices – about the architecture of digital currency infrastructure, about the regulatory framework for stablecoins, and about the role of the central bank as a trust anchor – will shape whether the future monetary system achieves the coordination and network effects that are the foundation of well-functioning money. A fragmented monetary landscape imposes costs on households and businesses in the form of higher transaction costs, reduced liquidity, and forgone gains from trade.

4 Concluding remarks

This paper has developed a formal economic framework for understanding why the decentralised consensus mechanisms at the heart of public permissionless blockchains lead to the fragmentation of the monetary landscape. The key mechanism is the coordination problem among validators: the strategic uncertainty facing each validator creates an irreducible cost of decentralisation. The more secure the blockchain (the higher the supermajority threshold for consensus), the higher must be the rewards paid to validators. Since these rewards must be borne by users through congestion rents, capacity constraints are a structural feature of decentralised systems. The result is fragmentation, as new blockchains with lower security thresholds emerge to serve users priced out of more secure chains.

Stablecoins were conceived as the bridge between the crypto ecosystem and the traditional financial system – a way to import the stability of fiat money into the programmability of the blockchain. The paradox is that the very infrastructure on which stablecoins are built – public permissionless blockchains – is structurally predisposed to fragment the monetary landscape that stablecoins are meant to unify. A USDC token on Ethereum and a USDC token on Solana are, in economic terms, different instruments: they settle on different ledgers, depend on different validator groups, and cannot be seamlessly exchanged. The stablecoin market has grown rapidly, with transaction volumes rivalling those of traditional payment networks.[6] But this impressive growth masks a deeper problem: the stablecoin ecosystem is not a single monetary network but a collection of chain-specific silos, each with its own liquidity pool and its own coordination dynamics.

[6] CoinGecko stablecoin dashboard, `https://www.coingecko.com/en/categories/stablecoins`.

Stablecoin regulation can address some issues, but the fragmentation problem lies in the rails, not in the regulation. A well-regulated stablecoin on a fragmented infrastructure is still a fragmented instrument.

The analysis of this paper underlines the importance of going back to the basics of money as a coordination mechanism. The classical insight – from Menger to Jevons to Kiyotaki and Wright – is that money is valuable because of the breadth of its acceptance network. The modern insight, developed here, is that decentralised consensus mechanisms systematically undermine this breadth by fragmenting the user base across competing platforms. The feedback loop runs in the wrong direction: instead of greater acceptance leading to greater use (the virtuous circle of money), congestion on one chain leads to exit to another chain.

This is not to deny the genuine innovations of blockchain technology. Programmable money, automated settlement, transparent ledgers – these are real advances that could improve the efficiency and inclusiveness of the financial system. But these innovations do not require decentralised consensus among anonymous validators. They can be implemented on unified ledgers anchored by central banks, which benefit from the institutional trust of the traditional monetary system.

Ultimately, the analysis in this paper points to the enduring importance of institutional trust in the monetary system. A purely decentralised monetary system, without the anchor of a trusted central authority, is structurally predisposed to fragmentation. The question for policymakers is whether the genuine innovations of blockchain technology can be harnessed while preserving the institutional foundations that make a unified monetary system possible.

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A Appendix: Laplacian beliefs at the switching point

This appendix provides a proof of the proposition that a validator who has cost $c_i = c^*$ has Laplacian beliefs over the proportion of other validators who contribute to governance services.

We assume a diffuse (improper uniform) prior on the common cost c, which is the standard assumption in the global games literature (Carlsson and van Damme (1993), Morris and Shin (2003)). We also restrict attention to threshold strategies, in which each validator contributes to governance if and only if c_i falls below a critical level. Standard arguments in the global games literature show that any equilibrium must take this threshold form: the payoff to contributing is monotonically decreasing in own cost c_i (contributing is less attractive the higher the cost) and monotonically increasing in the proportion κ of other contributors (contributing is more attractive the more others contribute). These monotonicity conditions ensure that the best response to any threshold strategy is itself a threshold strategy, and iterated deletion of strictly dominated strategies yields a unique surviving strategy profile.

A validator's reasoning takes account of:

- uncertainty over the common cost c
- uncertainty over the proportion κ that contribute to governance

The fact that a validator is indifferent between providing governance services and opting out suggests that the validator holds certain beliefs about the proportion of other validators who contribute. What are these beliefs?

The key point is that the uncertainty in question is *strategic uncertainty* – uncertainty over the proportion of validators who contribute to governance. What happens to strategic uncertainty as $\varepsilon \to 0$?

Consider the following question.

(*) **Question.** My signal is exactly c^*. What is the probability that proportion z or less of the validators contribute to governance?

The answer to this question gives the cumulative distribution function over the proportion who contribute, conditional on c^*, evaluated at z. Denote it by

$$G(z|c^*) \tag{10}$$

If we can obtain $G(z|c^*)$, we can differentiate it to obtain the density over the proportion who contribute.

Two steps to answer question (*).

Step 1. If the common cost c is higher than some benchmark level c_0, then the proportion of validators who have costs lower than c^* is z or less. This benchmark state c_0 satisfies:

$$\frac{c^* - (c_0 - \varepsilon)}{2\varepsilon} = z \tag{11}$$

Or

$$c_0 = c^* + \varepsilon - 2\varepsilon z \tag{12}$$

Step 2. So, the answer to question (*) is given by the probability that the true state is higher than c_0, conditional on signal c^*. This is,

$$\begin{aligned} & \frac{(c^* + \varepsilon) - c_0}{2\varepsilon} \\ = & \frac{(c^* + \varepsilon) - (c^* + \varepsilon - 2\varepsilon z)}{2\varepsilon} \\ = & z \end{aligned} \tag{13}$$

In other words, the cumulative distribution function over the proportion of contributors is the identity function, implying that the density function over the proportion of validators who contribute to governance is *uniform* over $[0, 1]$.

As $\varepsilon \to 0$, the uncertainty concerning c dissipates, but the strategic uncertainty is very severe. The marginal validator, who is nearly certain of the common cost, nevertheless holds maximally diffuse beliefs about the proportion of other validators who will contribute. This is the Laplacian property: the beliefs of the marginal validator are uniform regardless of the precision of private information.

It is this property that yields the clean characterisation of the switching point in equation (3) and ensures that the equilibrium is unique. The Laplacian property holds in the limit as $\varepsilon \to 0$ and provides the foundation for the global games solution of the coordination game.

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