

# Beyond Hurwicz

## Incentive Compatibility under Informational Decentralization

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### **Abstract**

Achieving incentive compatibility under informational decentralization has long been considered an impossibility in economics and computer science. We show this is conditional by identifying a subset of non-revelation-equivalent mechanisms that infer enforcement preferences indirectly from parallel, uncorrelatable games.

## **1 Introduction**

If we read the *Churning of the Milk Ocean* as a Hindu creation myth, what surprises is not so much that a price must be paid for setting the world in motion, but that the cost cannot be borne by the gods acting in the field of creation. Before time allows its deeper treasures to emerge, external authority is needed — Shiva — to stabilize the system.

Hurwicz echoes this structural constraint in his foundational papers on implementation theory, arguing that whenever participants can mislead others about their preferences, incentive compatibility requires an

external authority to punish deviations. Hurwicz saw this as a fundamental impossibility result, and concluded it made incentive compatibility impossible in all informationally decentralized systems lacking authorities to enforce transfers.

These results show that the difficulty is due not to our lack of inventiveness, but to a fundamental conflict among such mechanism attributes as the optimality of equilibria, incentive-compatibility of the rules, and the requirements of informational decentralization.<sup>1</sup>

Designers have accepted these arguments rather than confronting them directly. Where auctions have required protection against agents “changing their minds”, designers have generally relied on courts, auctioneers, or institutions to verify and punish attempts at revision. Such external authorities do more than levy penalties: they determine the *numéraire* in which agents are penalized, forcing stabilizing punishments outside the scope of the mechanism as necessary and creating a cost-bearing constraint that agents cannot neutralize from within it.

There is, however, a narrow class of non-revelation-equivalent indirect mechanisms in which enforcement costs can be generated endogenously. In these designs, agents who attempt to shift equilibrium strategically must bear exposure to uncertainty over time, and this exposure cannot be neutralized from within the mechanism. These mechanisms lie just beyond the boundary identified by Hurwicz.

This paper explains how such solutions are possible. It starts with theory: why circular mechanisms are unstable, and how designers stabilize them by introducing enforcement costs that do not respond to strategic play. It then shows it is possible to make these constraints responsive to play without making deviation rational — through design techniques which force agents to pay front-loaded costs under uncertainty when proposing changes that will shift equilibrium security levels in the mechanism. This permits incentive compatibility to emerge in ways that are unimplementable in direct or revelation-equivalent mechanisms.

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<sup>1</sup>Hurwicz, L. (1972). On the design of mechanisms for resource allocation. *American Economic Review Papers & Proceedings*, 62(2), 1-30.

## 2 A Special Class of Circular Mechanisms

In the canonical definition provided by Hurwicz (1972), a mechanism is simply a function that maps actions or messages to outcomes. Whether a mechanism is incentive compatible depends on whether its outcomes implement a social choice rule as defined by Arrow (1951), and later Gibbard and Satterthwaite (1973, 1975) and Maskin (1977).

It would take almost a decade before Myerson showed that under certain conditions indirect mechanisms can be reduced to direct ones without loss of generality (1979)[6]. The sheer power of his Revelation Principle would later induce many to see indirect mechanisms as essentially interchangeable with direct ones. But in the early 1970s, this suspicion had yet to take root, and Hurwicz framed his definitions to cover games in both classes. Nor did he presuppose any particular environment or specify how messages be communicated.

Rather, Hurwicz defined a mechanism as incentive compatible when, given the rules of the game, each agent finds it optimal to act in a way that implements the intended social choice rule. The circular mechanisms studied here fall squarely within this definition. They map actions into outcomes. What distinguishes them from other mechanisms is a structural property: they operate in rounds with the results of early stages reappearing as constraints on later play.

For this reason, circular mechanisms should not be confused with repeated games that extend over time. While circular mechanisms share similarities with such games, what makes them uniquely vulnerable is that their own enforcement penalties – the costs that punish deviations – can be strategically manipulated within the game. Agents who learn how the game handles enforcement can deliberately weaken it to enable deviation at lower cost.

Such mechanisms appear across many domains: as continuous double auctions and adaptive market-clearing processes in economics; as reputation systems and agenda-controlled games in political science; and as gossip protocols, adaptive routing, and consensus mechanisms in computer science. Appendix A provides a representative taxonomy.

Existing research covers these games as well. Because their incentives are path-dependent, we know players evaluate strategies over histories rather than in isolation (Abreu, Pearce & Stacchetti; Fudenberg & Levine; Fudenberg & Maskin)[16, 17, 20]. Players may also reassess ear-

lier choices in a phenomenon known as *time inconsistency* (see Strotz; Pollack; Hicks; Kydland & Prescott), which is destabilizing not only because agents may want to revise plans, but because the possibility of revision may be anticipated (Hart & Tirole; Dewatripont; Barro & Gordon). Incentive compatibility can fail even if all parties regard the unrevised outcome as mutually beneficial (Farrell & Maskin; Maskin & Moore)[21, 22].

The problem with *ex post revision* is that it creates the same need for a credible punishment that Hurwicz identified in static settings. Hurwicz assumed such punishment was impossible in decentralized environments lacking institutions capable of observing and punishing inconsistency. His logic extends naturally to dynamic games with incentives for revision, making it surprising that circular mechanisms can eliminate this problem.

Yet the solution is oddly anticipated in a subset of theoretical papers. The most striking is James Jordan’s discovery that when incentive compatibility is unattainable in one-shot mechanisms, it can re-emerge in path-dependent indirect mechanisms.[10, 11] Jordan does not argue that the solution requires circularity, but demonstrates that any solution must distribute costs over time. He also anticipates later work showing that direct mechanisms can fail to implement equilibria available to indirect ones (Aumann; Renou & Tomala; Strack & Mora; Attar)[12, 13, 14, 15], and that incentive compatibility can be restored by leveraging expectations of future payoffs in their enforcement structure (Maskin & Moore; Abreu, Pearce & Stacchetti).

The remainder of this paper shows how a narrow subclass of mechanisms can fulfill these criteria by creating a dual-enforcement regime that allows the mechanism to optimize its own security function by observing it indirectly in the revealed preference players show to coordinate beyond the scope of its enforcement guarantees.

### 3 Endogenous Unactionability

Sifting through paper after paper, we can see that where incentive compatibility survives informational decentralization, it is because the mechanism embeds a constraint that agents must bear but cannot neutralize. For the rest of this paper, we refer to this property as *endoge-*

*nous unactionability.*

In mechanisms where external authorities punish deviation, endogenous unactionability emerges trivially, as enforcers have no utility function in the mechanism. Authorities must still be immune to strategic manipulation, but this is handled by requiring them to verify any public states used to determine allocations or transfers. This explains one of the reasons circular mechanisms can appear counterintuitive: opacity – not transparency – is what enables enforcement.

In computer science, many decentralized protocols exist which implement outcomes, and some accomplish this without adding trusted authorities. Are they not incentive compatible? The answer is no in the sense that each known solution only achieves convergence by fixing at least one cost-imposing dimension of the environment so that it cannot respond to strategic pressure. This is different from the challenge posed by Hurwicz, who asked whether mechanisms could incentivize a stable enforcement function, not assume one into existence beyond the game.

In games that converge through repeated play with Bayesian updating, achieving agreement requires agents to update beliefs about a fixed state space with common priors and stationary likelihoods (Milgrom & Roberts; Fudenberg & Levine).[19, 18] Agreement can also be induced through public randomness or correlated devices, but such approaches work where randomness is unintelligible and thus unactionable as in Myerson’s *Great War* paper or Aumann’s correlated equilibrium.[9, 12] Deviation in these approaches is only costly once incorrect beliefs can induce suboptimal outcomes, so coordination unravels once agents can influence signal generation, timing, or interpretation.

This same problem characterizes mechanisms that rely on fixed type distributions, posted prices, or deterministic rules. Games that exploit Byzantine fault tolerance, posted-price structures, or fair schedulers are only stable when honesty, prices, and timing are strategically insulated: once those dimensions are endogenized, security and convergence collapse. Approaches leveraging regret minimization and multiplicative weights exhibit the same structure: they require stationary payoffs and non-strategic feedback, and cycling reappears as soon as agent actions reshape allocations.

Across all cases, designers implement outcomes by asserting load-bearing structures that resist strategic manipulation, not optimizing the enforcement function itself through strategic play. Incentive compati-

bility requires the latter, but this seems absurd: how can costs be both endogenously generated and non-manipulable? Such opacity is self-evidently impossible in direct mechanisms, where implementability demands truthful preference revelation and the need for Maskin monotonicity further prevents agents from commingling multiple values into non-scalar reports and sharing their preferences obliquely. Any solutions must therefore lie outside the class of direct mechanisms or their revelation-equivalent indirect counterparts.

As we shall see, the techniques which create endogenous unactionability do in fact block reduction under the Revelation Principle. But discussing how indirect mechanisms can preserve opacity requires a way to reason about how mechanisms can protect informational privacy. To provide these, our next section introduces the concepts of *Myerson* and *Non-Myerson Layers* to show how constructs composed of the latter can sustain the kinds of compartmentalization which block agents from verifying the true preferences of other agents in the mechanism, even while aggregating their underlying preferences into a shared enforcement cost.

## 4 Myerson and Non-Myerson Layers

The Revelation Principle is a brilliant analytical reduction which demonstrates that many indirect mechanisms can be reduced to simplified games in which agents report types, the mechanism selects an outcome, and transfers enforce truthful revelation. Within its domain, the principle provides extraordinary clarity, allowing designers to reason about incentives without worrying about the structural compartmentalization or passage of time in a game.

Yet many non-revelation-equivalent games exist which cannot be reduced to direct mechanisms without breaking incentive compatibility. The techniques that block reduction are fairly easy to implement technically, including strategic routing (Renou & Tomala), some probabilistic lotteries (Strack & Mora), and asymmetric information disclosure (Attar). Claims of universal reduction only hold under restrictive assumptions that exclude these phenomena.

These non-revelation-equivalent strategies become meaningful when mechanisms are treated as *constructs* composed of multiple layers. In such

designs, each layer can serve a different function, yet condition on inputs from previous layers and create outputs for subsequent ones. A boundary between layers exists at any point where inputs are strategically indistinguishable from randomness when analyzed in isolation.

For clarity, we call a layer a *Myerson Layer* if its incentive structure can be faithfully represented by a reduced game that acts on direct-type reports and has verifiable outputs. These layers follow the same rules as direct mechanisms and, when chained together in sequence, may be analyzed as if occurring simultaneously even though it may require time to conclude.

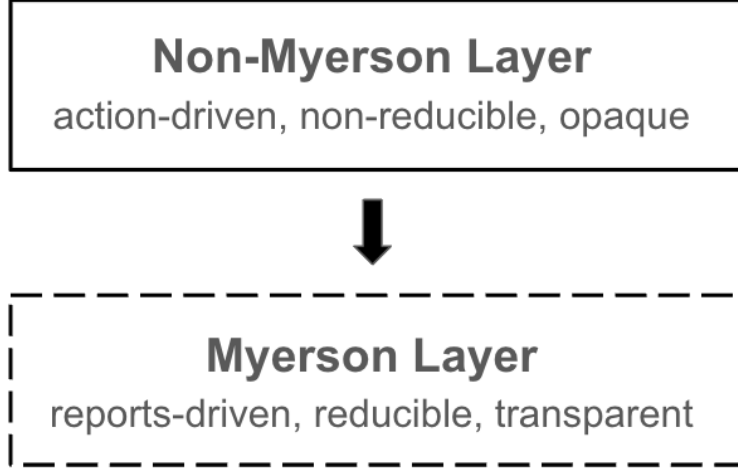
In contrast, a *Non-Myerson Layer* has the properties of non-revelation-equivalent indirect mechanisms, relying on forms of action within the mechanism that do not admit reduction without loss of essential structure, and producing outputs that encode preferences obliquely.

The distinction matters with circular mechanisms, as any sequence of Myerson Layers collapses into a single Myerson Layer under the Revelation Principle, but constructs with Non-Myerson Layers are irreducible because the informational structure of at least one layer blocks reduction to direct type reports.

This makes *constructs* useful conceptual tools for conceptualizing where the demand for credibility and supply of enforcement happen in circular mechanisms. In classical designs reliant on external authorities, enforcement is typically provided by upstream institutions that project outputs downstream where they appear as exogenously-fixed honest types or other constraints. This is shown in Figure 2, which shows a *Non-Myerson Layer* preceding a *Myerson Layer*.

Such arrangements can affect the viability of trade-offs in downstream layers. A canonical example is budget balance in the Myerson-Satterthwaite setting, where adding a trusted auctioneer implicitly assumes an upstream layer to incentivize its provision. When this layer is removed in revelation-equivalent constructs, budget balance fails downstream as the mechanism must internalize the cost of generating enforcement that was previously incentivized externally.

Constructs in which Myerson Layers project information into Non-Myerson Layers are rarer, but can be useful when the second layer introduces opacity, delay, or strategic aggregation to the preferences revealed in the first, transforming the original inputs into signals that emerge staggered in time. An example is sequential voting systems with



**Figure 1. Non-Myerson Layer preceding Myerson Layer.** The Myerson layer conditions on preferences expressed in the preceding layer which appear projected into it in forms indistinguishable from randomness.

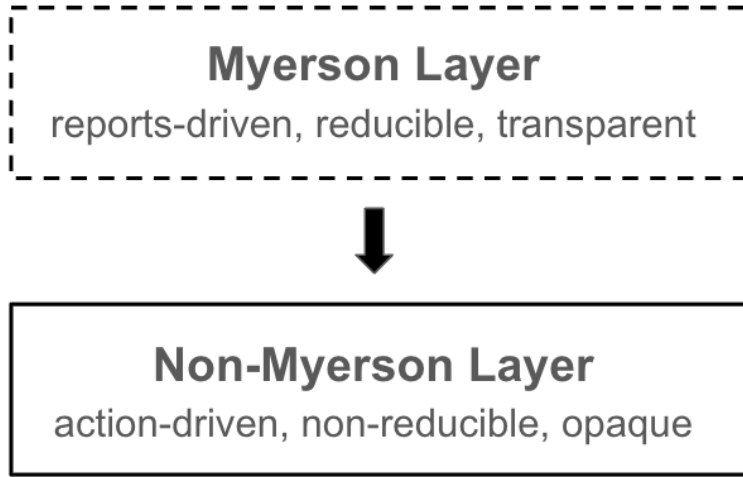
portfolio assembly, where individual votes cast in the first layer may not be immediately visible in the outputs of the second. Blockchains with private mempools show how this design can add obfuscation and delay which frustrates attempts to reconstruct whose preferences are reflected in aggregated outcomes at any point in time. This is depicted in Figure 1, which shows a *Myerson Layer* preceding a *Non-Myerson Layer*

These differences become decisive when layers are chained into circular constructs. Consider a construct consisting solely of Myerson Layers, which the Revelation Principle collapses into a single layer in which outputs from any round are transparent inputs to the next, as shown in Figure 3.

Circular mechanisms with multiple Non-Myerson Layers are needed to preserve forms of informational compartmentalization. While each layer still acts on information projected into it from previous layers, its inputs need not be reducible to direct type reports and may include the non-scalar outputs of previous layers that preserve ambiguity of intent. This is shown in Figure 4.

Across the lossy informational boundaries that separate layers in these constructs, which we call *privacy walls*, agents can observe actions with-





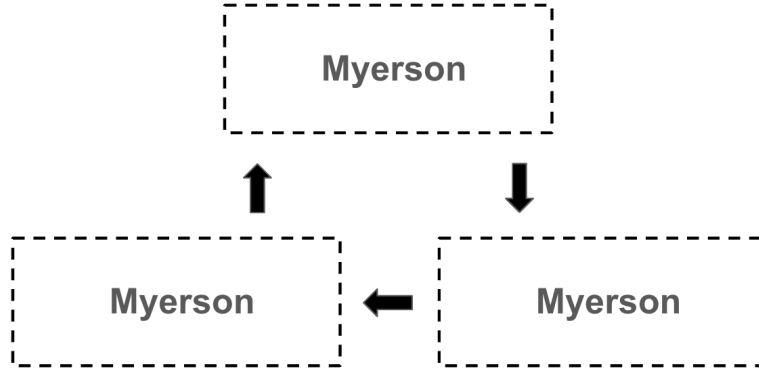
**Figure 2. Myerson Layer preceding Non-Myerson Layer.** The Non-Myerson layer acts on transparent inputs projected into it from the previous layer, and is able to reconstruct the intent behind the projected preferences.

out reconstructing intent. They must, in effect, peer through a glass darkly. In the next section, we show how these privacy walls combine with non-scalar values to enable a new type of strategy that re-opens the door to incentive compatibility in conditions of decentralization.

## 5 From Privacy Walls to Selective Disclosure

Because direct mechanisms are evaluated in a static frame, the Revelation Principle forces its circular mechanisms to operate sequentially, as anything else implicitly breaks reduction (Myerson, 1986). Multiple layers may operate in parallel in non-revelation-equivalent mechanisms, however, permitting *selective disclosure strategies* to emerge, where agents pierce privacy walls and reveal preferences directly to other participants.

Such disclosures exist in many auction designs. They are common in *off-book trading mechanisms*, where players must choose between submitting anonymous limit orders to a central book or negotiating privately with dealers “upstairs”. They also appear in FCC-style spectrum auctions, where players may tacitly disclose geographic priorities. In



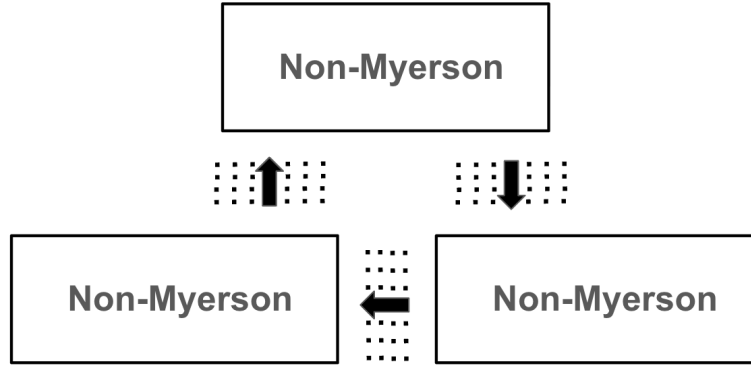
**Figure 3. Direct Mechanism as a Construct of Myerson Layers.** Multiple Myerson Layers chained into a circular construct form a Penrose-style mechanism which is locally coherent but globally incoherent.

blockchains, similar disclosures occur whenever users sell transactions to miners in return for privately negotiated benefits.

As in other mechanisms, strategies involving the disclosure of preference maps create a two-sided risk. Agents who offer sincere interpretations expose themselves by making their internal structure legible, while agents who receive disclosures face the risk of strategic manipulation. A blockchain user who sells transactions to a miner may be signalling interest in discounted inclusion, but their true objective may be to lower overall security and make deviations cheaper within the mechanism. An informed counterparty may rationally decline such a trade.

Because the act of piercing a privacy wall connects otherwise compartmentalized information spaces, and the base-layer mechanism only penalizes deviations involving non-scalar outputs from those compartments, selective disclosure strategies create new meta-games outside the mechanism’s core enforcement regime. Players have a strategic choice of which regime to use for preference revelation, and the economic consequences of deception can vary based on which communication channel is chosen.

The non-scalar messages that protect privacy on the base layer then reinforce the informational integrity of the meta-game, as players engaging in strategic disclosure cannot provide verifiable evidence of consistent beliefs with their preferences as revealed obliquely under the



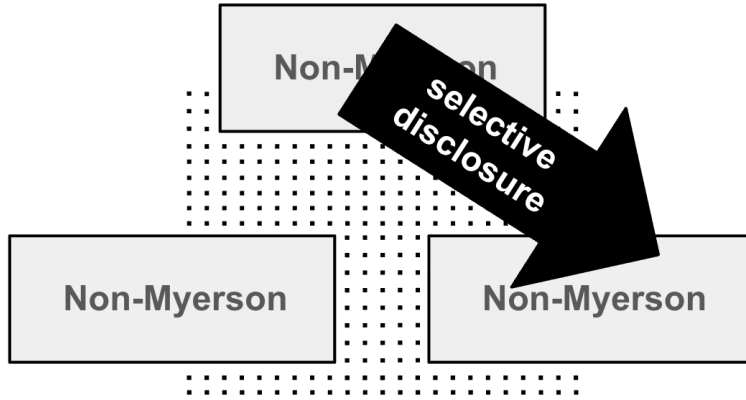
**Figure 4. Indirect Mechanism as a Construct of Non-Myerson Layers.** Multiple Non-Myerson Layers chained into circular constructs lose verifiability as privacy walls form between layers.

main enforcement regime. Where the mechanism makes playing such games rational for participants, it essentially induces kenosis: pulling away from players to create a safe space for them to interact that it cannot observe, but that will let it intuit, insulated from its influence, the marginal utility of its own enforcement function.

To see the solution more clearly, consider a case where Alice asks Bob to take an action that lowers security in the mechanism. From Bob's perspective, Alice may be attempting to convert a global public good (security) into a dyadic trust good, capturing the savings while Bob absorbs the risk. Alternatively, her offer may be sincere, with Alice offering Bob benefits for helping her lower in-mechanism security.

And while some may argue that Bob lacks all rational grounds to judge Alice's proposal, we cannot restrict Bob deciding himself on the basis of his private preferences. The mechanism may not be able to observe those directly, but Bob is the decision-maker who determines their relevance. And there is no harm to letting him do so, for if Bob already prefers lower security, he needs no persuasion. Alice's suggestion only becomes decisive in the exact case when Bob's strategy changes based on it. And in that case her lack of credibility justifies his maintaining a high-security equilibrium, while his trust in her rationalizes lowering it.

From the perspective of the mechanism, Alice is opening a Non-Myerson Layer whose output and existence is opaque to the base-layer, operates



**Figure 5. Selective Disclosure as Communications Strategy.** Agents pierce privacy walls and communicate preferences directly through Non-Myerson meta-games the mechanism encourages to be created in private channels where speech is not tracked or penalized, but whose output is a structured input returned to the mechanism which drives the mechanism into equilibrium. This makes it a part of the underlying game, not the "null case" of player "exit" or "opt-out" as retreats to non-enforcement environments are traditionally modelled in implementation theory.

under a different enforcement regime and results in a non-scalar output that is indistinguishable from one produced under the base-layer, and will invisibly commingle Bob's other preferences with his assessment of her credibility. The mechanism can see Bob's choice without knowing what preferences motivates it. But it does not need this information: if Bob trusts Alice when its enforcement regime could protect him from loss, its level of protection is excessive.

The mechanism is essentially inducing a counterfactual game it cannot observe, one which nonetheless signals the marginal utility of its own enforcement function back to it in a form indistinguishable from normal gameplay. And this signal is credible precisely because Alice cannot cite any verifiable action taken under the mechanism's enforcement regime as evidence of her credibility. Were such a link possible, Bob could assign probabilities to Alice's sincerity and uncertainty would collapse into risk, correlating the two games and destroying the informational separation required for inference.

For readers accustomed to direct mechanisms, it may seem counterintu-

itive that a mechanism never observes the preferences that are decisive. But it does not need to. When enforcement levels are above equilibrium, private communications are cost-saving and attractive. As they converge toward equilibrium, the risks of disclosure grow while its benefits shrink, and disclosure strategies become less attractive on the margin. The mechanism essentially incentivizes retreat to alternate enforcement regimes in the proportion needed to drive its marginal utility of enforcement into optimal equilibrium.

Yet these selective disclosure strategies exist only in non-revelation-equivalent mechanisms. In the next section we show this formally, demonstrating that no direct report Alice can offer Bob avoids collapsing into epistemic claims whose credibility cannot be established within the mechanism itself.

## 6 Epistemic Uncertainty from Unrepresentable Values

Throughout this paper, we use *uncertainty* in the sense articulated by Knight, Keynes, and G. L. S. Shackle: not as a variable that can be calculated or approximated probabilistically, but as *unknowability* – the absence of any representation that can be rationalized within an internally coherent evaluative framework. As Keynes famously wrote:

The sense in which I am using the term is that in which the prospect of a European war is uncertain... or the price of copper and the rate of interest twenty years hence... About these matters there is no scientific basis on which to form any calculable probability whatever.<sup>2</sup>

For the sake of convenience, we refer to whatever variable motivates agents to accept or reject selective disclosure proposals as *trust*. This is not meant as an ontological statement. We do not attribute moral qualities to trust, nor deny that it may be the product of utilitarian calculation. We merely name a variable that motivates action when enforcement levels are decisive at the margins. So we state that an agent

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<sup>2</sup>Keynes, J. M. (1936). *The General Theory of Employment, Interest, and Money*, Chapter 12. Macmillan.

acts on trust whenever they accept that statements offered by a counterparty may be false, yet prefer to act as if they are true. Agents who withhold trust prefer to assume statements may be false and instead rely on the baseline guarantees enforced by the mechanism.

This approach contrasts with much modern work in computer science, which seeks to eliminate uncertainty by expanding the state space through additional parameters, beliefs, or utility dimensions. We do not dispute the usefulness of such methods, but deny that they can achieve endogenous unactionability.

The reason is that regardless of how one conceptualizes trust – whether as a psychological variable or a non-scalar value that can be formally modelled – representing it as a direct type to the base-layer collapses the information it is meant to convey. The problem is connected to the way security and trust become substitutes across uncorrelated games when agents have the option of lowering enforcement costs in one by extending trust in another. We can show this formally.

### 6.1 Trust as an Unparameterizable Domain Space

In informationally decentralized systems such as consensus mechanisms, deviation must be discouraged without recourse to external enforcement. Generating security is therefore costly. Let  $S \geq 0$  denote the level of security imposed by the mechanism, with cost function  $K(S)$ , where

$$K'(S) > 0.$$

Let  $\tau$  denote the *trust environment*: an aggregate property capturing how willing participants are to refrain from deviation absent strong enforcement. Let  $R(S, \tau)$  denote residual cheating risk, where

$$\frac{\partial R}{\partial S} < 0, \quad \text{and} \quad \left| \frac{\partial R}{\partial S} \right| \text{ decreases as } \tau \text{ increases.}$$

Trust and security are substitutes in this environment: trust reduces the marginal utility of additional enforcement. When Alice proposes that Bob cooperate with her to reduce security, she is implicitly suggesting that welfare can be jointly increased by reallocating resources from enforcement to other forms of utility at the margin.

Welfare improvements require changing the socially optimal level of security, which solves

$$\min_{S \geq 0} K(S) + R(S, \tau),$$

with first-order condition

$$K'(S^*) = -\frac{\partial R(S^*, \tau)}{\partial S}.$$

It follows immediately that the optimal security level  $S^*(\tau)$  is strictly decreasing in  $\tau$ .

## 6.2 The Trust Parameter Cannot Be Elicited

To compute  $S^*(\tau)$ , the mechanism must know  $\tau$ . In systems with external authorities, this information may be inferred institutionally. In informationally decentralized mechanisms, however, the mechanism would need to elicit  $\tau$  as a type.

This is impossible.

A declaration of the form “my trust level is  $\tau$ ” cannot distinguish a genuinely high-trust agent from a low-trust agent strategically claiming higher trust in order to reduce penalties. The type and its anti-type generate identical messages.

## 6.3 Gödel-Type Collapse

While any informationally decentralized mechanism that must optimize its own enforcement levels requires  $\tau$ , any attempt to represent it directly is strategically manipulable in exactly the dimension it is meant to measure. Encoding trust destroys its informational role. This is a Gödel-type phenomenon: certain economically necessary variables are unrepresentable within mechanisms because any attempt to encode them renders the encoding meaningless.

This collapse creates *fundamental uncertainty*. The mechanism requires  $\tau$  to compute  $S^*(\tau)$ , but  $\tau$  cannot be known ex ante, inferred from reports, or represented within the mechanism without contradiction. This is not epistemic ignorance resolvable through learning; it is structural.

The mechanism cannot observe the counterfactual worlds in which different trust levels would have prevailed, nor price security optimally without exposing itself to over- or under-enforcement.

At first glance, this conclusion may seem too strong. One might object that the determinants of credibility may be discovered and formalized. And if credibility is eventually discovered to be a well-defined variable, why can it not be elicited by the base layer directly?

Except our challenge is not whether credibility can be defined, but whether it can be made *actionable* within the base layer without breaking incentive compatibility. And while a mechanism could theoretically condition enforcement on well-defined types, it would need to filter its reports to privilege credible agents. And this would exclude the preferences of non-credible agents from aggregation, driving enforcement costs away from social optimal levels. Incentive compatibility requires optimizing over all preferences, not merely a subset of trusted players.

And if correlation is possible despite a lack of semantic definition? In such a case there apparently exists a positive, exploitable correlation that motivates selective disclosure strategies. In that case, misrepresentation is profitable at the margin, and agents who extend trust are systematically exploited until they update their beliefs defensively until the correlation no longer supports profitable inference. And in equilibrium, the only stable such point is when the correlation is zero at the margin.

#### 6.4 Uncertainty and Indirect Mechanisms

Indirect circular mechanisms are the only class capable of resolving this problem, because they allow participants to play games in parallel under different enforcement regimes and treat the outcome as a counterfactual judgment on the marginal utility of enforcement within the mechanism.

Within each game, the other appears as a Non-Myerson Layer whose output is opaque and subject to misinterpretation. Each nevertheless serves as a venue in which rational judgment may be expressed. And while preferences and cognitive frameworks agents use may differ across layers, actions remain credible across them, as representations in the parallel game are penalized on the base-layer.

In this way, indirect mechanisms convert an unrepresentable param-



ter into an observable gradient without collapsing uncertainty into a reportable type. The solution is unimplementable without a base-layer game consisting of Non-Myerson Layers that generate privacy walls, invite agents to bypass them, and treat the result as an opaque referendum on the efficiency of the allocation of resources to the enforcement regime of the mechanism.

It follows that any informationally decentralized mechanism that must optimize its own enforcement levels cannot be direct. What it must observe is a Gödel-type object: fleeting, disguised, mixed invisibility into a non-scalar message and appearing only when decisive. And structurally impossible to represent directly, despite being capable to incentivize and subject to rational consideration.

## 7 From Uncertainty to Incentive Compatibility

This paper began with a narrow problem: how incentive compatibility can be sustained in informationally decentralized environments. In the preceding sections we showed that the solution lies in the endogenous generation of costs that agents cannot neutralize within a mechanism, and that this is possible in action-based mechanisms with non-scalar messages and privacy walls.

Selective disclosure plays a decisive role in this process and yields its simple equilibrium logic. When enforcement is too strong, agents have incentives to cooperate to reduce unnecessary security costs. When enforcement is too weak, agents retreat to trust-free strategies and demand stronger guarantees, preferring strategies that provide greater protection against revision. Once enforcement is correctly calibrated, neither revealing nor concealing private structure can improve expected welfare, selective disclosure ceases to be profitable, and security remains stable in equilibrium.

Seen in this light, uncertainty is not an epiphenomenon but the functional substitute for external authority in decentralized systems. And incentive compatibility can emerge more generally as self-stabilizing security levels now provide a common *numéraire* against which other forms of utility can be expressed. Appendix D shows a practical example of a mechanism exhibiting this dynamic.

The technique may only be implementable within a narrow subclass

of indirect mechanisms, but it exists. In the next section, we revisit the large body of impossibility results in computer science and economics which claim it cannot, showing that their conclusions exclude indirect mechanisms by assumption, often for reasons their authors do not recognize can be relaxed.

## 8 Explaining Impossibility

Across economics and computer science, impossibility results share a common premise: that all strategic interaction occurs under a single enforcement regime. The edifice of mechanism design incorporates this assumption: excluding the possibility that agents might rationally shift coordination into lower-security domains created by the mechanism itself.

This possibility was invisible to early theorists. Because Hurwicz examined allocation in environments whose setting was practically indistinguishable from the state of nature, he never considered that successful implementation might create an enforcement regimes from which strategic retreat might be possible. His impossibility result is therefore correct for the class of mechanisms he analyzes, but does not extend to mechanisms that give agents the freedom to coordinate under reduced enforcement guarantees, and incentivizes them to do so for its own purposes.

Other impossibility results rest on the same assumption. Arrow’s impossibility theorem, the Gibbard–Satterthwaite result, and Maskin’s monotonicity condition all presuppose that preferences must be represented as semantically meaningful scalar reports, that communication is verifiable, and that deviation is disciplined by a symmetry of enforcement costs. These results do not assert that incentive compatibility is impossible in informational decentralization per se, but they encourage the conclusion that strategic interaction must occur under a single enforcement regime.

Canonical results from computer science reinforce the same assumption. Developed in foundational papers by Lamport, Shostak, and Pease, and later formalized by Bracha and Toueg, results on the limits of adversarial tolerance assume that algorithms behave according to fixed rules and execute changes as *atomic steps*. [35, 36, 37] These models implicitly

treat actions as costless, uncertainty as absent, and assume deviation cannot be punished through exposure accumulated over time. Later results such as the FLP theorem operate in this same framework, in which non-termination and inconsistency arise because no mechanism can impose asymmetrical costs that diverge over time.

In more recent work, including the so-called TFM literature, we find further arguments discouraging attention to indirect mechanisms as a viable solution class, with some authors even asserting analysis can be entirely restricted to the study of direct mechanisms. Many of these results fail to generalize due to improper reduction under the Revelation Principle, often from changing a two-sided, multi-parameter and dynamic game into a one-sided, single-parameter, static auction that cannot even in theory implement the same set of outcomes. A contributing source of difficulty is that off-chain coordination in TFMs naturally invites action under multiple enforcement regimes, which is interpreted to suggest the presence of multiple direct mechanisms rather than circular constructs with interacting non-revelation-equivalent layers.

Related work inherits these restrictions implicitly through modeling choices. Bayesian analyses assume that learning takes place over static distributions within a single enforcement framework. Posted price models presuppose endogenous unactionability under highly restrictive conditions. And the pervasive assumption that miners “faithfully implement” protocols is repeatedly used to avoid eliciting preferences from them, an omission that leads to recurring problems with interdependent valuations once miners re-enter the game as strategic players. These results generate impossibility not because their incentives are ill-posed, but because their frameworks were only intended to handle direct mechanisms, not indirect constructs with multiple interacting Non-Myerson Layers.

Philosophically, the category error that emerges is the inverse of that identified by Gilbert Ryle in *The Concept of Mind* (1949). In that book, which popularized the phrase “ghost in the machine,” Ryle critiqued Descartes for assuming the existence of an immaterial spirit simply because the mind seems to have agency. The error in our time is reversed: analysts retreat to deterministic models because networks are made of machines. Impossibility reappears quietly because deterministic execution cannot accommodate semantic ambiguity.

This same pattern appears in economic papers on the limits of permissionless consensus, where economists import constraints from computer

science as fixed technical limits and then restrict possibility within those bounds. Some papers assume verifiability is needed for incentive compatibility when that is not the case, as with Groves-Ledyard or dynamic pivot mechanisms. Others argue that consensus mechanisms must be voting systems, treating verifiability and voting-like behavior as necessary primitives and excluding stabilizing forms of off-chain coordination by assumption.

But this suggests a puzzle: if indirect mechanisms can in principle escape classical impossibility results, why has the literature repeatedly failed to converge on them? Why do attempts to relax these assumptions so often conclude that nothing fundamental changes?

## 9 The Gravity Well of Direct Mechanisms

The answer seems to be that mechanisms governed by the Revelation Principle exert a strong cognitive pull. Once a model satisfies even a subset of its defining assumptions—costless communication, verifiable reports, fully specified state spaces—it is drawn back into what we call the *gravity well* of revelation, where mechanisms collapse into direct forms unless costs are imposed under uncertainty. This pattern appears repeatedly across the literature in a series of near-miss attempts to escape impossibility by relaxing dimensions of the standard framework one at a time.

**Time:** a large body of work introduces dynamics — rounds, epochs, repetition, or sequential interactions — yet preserves transparency, verifiability, and report-based reasoning. In these models, time functions as an index over observations rather than as a generator of uncertainty. Learning sharpens inference, beliefs converge, and temporal structure accelerates the collapse back into revelation-equivalent paralysis.

**Collusion:** many models enrich the strategy space by allowing agents to collude, coordinate, or form coalitions. This introduces high-dimensional preferences, but these cannot be used to implement social choice rules, as their existence generates productive ambiguity about agent motives and preferences for future payoffs. As a result, stabilizing forms of cooperation that increase welfare are removed alongside suboptimal collusion, and off-chain agreements are recast as behaviors to be detected, punished, and eliminated.

**Risk:** a prominent line of work attempts to impose costs by making attacks expensive through fees, slashing, or resource expenditure. When such costs can be priced *ex ante*, however, they enter agents' decision-making frameworks as risks over known states rather than as exposure to uncertainty over time. Deterrence then fails, as it is modeled through equilibrium selection rather than through forced exposure to front-loaded costs under Knightian uncertainty.

**Permission:** many proposals reintroduce trusted committees, governance layers, or validator sets. These moves can succeed precisely because they smuggle in additional Myerson or Non-Myerson Layers that live outside the layer under analysis. Yet because these changes are framed as shifts in trust assumptions rather than informational structure, they are treated as orthogonal to the incentive problem instead of as alterations that will also collapse once subject to systemic rationality.

**Stabilizers:** posted prices, fixed fee schedules, and deterministic inclusion rules appear to move away from the Revelation Principle by constraining behavior in other ways. In practice, they deepen the gravity well by making actions legible, deviations interpretable, and learning faster. They are steps toward direct mechanisms, not away from them.

**Authority:** the introduction of stakers, validators, and internal governance bodies shifts authority from the environment into the mechanism. Once authority becomes endogenous, however, control itself becomes a source of utility, and the mechanism is tasked with incentivizing its own enforcement, reintroducing the circular paradox diagnosed by impossibility results.

In retrospect, there is no smooth path from the direct world to the indirect one. The transition appears to require a discontinuous shift in perspective across multiple dimensions: reports versus actions, static versus dynamic mechanisms, scalar versus non-scalar messages, risk versus uncertainty, monotonicity versus non-monotonicity, verifiability versus privacy, and *ex ante* costs versus *ex post* benefits.

From the perspective of the direct mechanism, this leap is invisible. It requires abandoning too much analytic scaffolding to even conclude that the solutions are tractable. Approaches that rely on privacy appear incoherent in settings that demand verifiability, and some variables can only be made decisive by rendering them semantically meaningless. Matters are further complicated by the possibility that multiple cognitive models may coexist, pulling the concept of utility itself into

question.

As such, classical impossibility results are neither surprising nor discredited. They remain faithful descriptions of what occurs inside the gravity well of the Revelation Principle. From the perspective of the indirect mechanism, however, the direct mechanism emerges as the degenerate case in which impossibility arises because uncertainty is resolved immediately, a single enforcement regime is imposed by fiat, and values that matter become semantically impossible to express.

## 10 Conclusion

This paper began from a narrow question about incentive compatibility in distributed consensus and arrived at a broader reconsideration of how cooperation can be sustained without external authorities, showing the conditions under which incentive compatibility is possible.

Seen from this perspective, the power and the limits of the Revelation Principle become clearer. The principle is extraordinarily effective within the realm it was designed to govern: static or acyclic environments with costless speech and fully specified state spaces. But in indirect circular mechanisms where multiple enforcement regimes exist, improper reduction can strip away degrees of freedom by obliterating strategic ambiguity. Much like a black hole that collapses structural coherence at its event horizon, reduction transforms meaningful information into semantic indecipherability. Nothing essential can be lost only if nothing opaque mattered to begin with.

The broader implications are worth noting. In his *General Theory* (1936), Keynes extended Knightian uncertainty into macroeconomics, arguing that liquidity traps persist not because agents miscalculate risk, but because stasis prevails when uncertainty looms over the value of potential investments. On a more modest level, what has been missing in mechanism design is a way out of this same trap: a way for uncertainty to discipline behavior in ways that motivate price discovery instead of punishing it. By forcing agents to reveal strategic preferences for playing different games, indirect mechanisms can accomplish this, transforming uncertainty into a cost that can be rationally borne, shared, and priced without ever being fully resolved.

We believe that mechanism design must expand its vocabulary to in-

corporate these techniques and concepts. In mechanisms with routing strategies, variable-time hashing lotteries, and looping Non-Myerson constructs, sacrificing verifiability is not a defect but the price paid to sustain the forms of informational privacy that permit the mechanism to see its own value reflected indirectly in the willingness of actors to risk loss in its absence.

The lesson returns us, in many ways, to our mythological stories of creation. Where stabilizing costs can be paid outside a system, stability can follow. Where they cannot, they must be borne within the system in a manner that renders them external and incomprehensible to its own rational framework.

## A Terminology

This appendix collects and standardizes the key terms introduced in the paper. Its purpose is not to introduce new concepts, but to fix language so that ideas are referred to consistently and unambiguously throughout.

**Mechanism.** A mechanism is a process that specifies admissible actions, information structure, and outcome rules governing interactions between agents. Following Hurwicz, a mechanism maps actions or messages into outcomes.

**Incentive compatibility.** A mechanism is incentive compatible with respect to a social choice rule if, for each agent, acting according to the strategy prescribed by the mechanism is optimal given the strategies of others, so that the induced equilibrium implements the intended social choice rule.

**Direct mechanism.** A direct mechanism is one in which agents report types or preferences in a single interface, after which the mechanism selects an outcome and transfers enforce truthful revelation. Direct mechanisms are the canonical objects governed by the Revelation Principle.

**Indirect mechanism.** An indirect mechanism is one in which agents express preferences through actions taken within the mechanism rather than through direct type reports. Outcomes depend non-trivially on how actions are aggregated, sequenced, and interpreted.

**Construct.** A construct is a mechanism composed of multiple internally chained layers. Constructs, rather than individual layers, are the primary objects of interest in circular and self-referential mechanisms.

**Layer.** A layer is a subcomponent of a construct in which agents condition on inputs and project outputs into subsequent layers in ways that appear to be unactionable when layers are studied in isolation.

**Myerson Layer.** A Myerson Layer is a layer whose incentive structure can be faithfully represented as a direct mechanism acting on type reports and projecting its output as publicly observable randomness or state changes. Any sequential composition of Myerson Layers may be reduced to a single Myerson Layer under the Revelation Principle.

**Non-Myerson Layer.** A Non-Myerson Layer is a layer whose incentive structure is not revelation-equivalent. Such layers rely on action-based incentives, ambiguous signals, dynamic preference aggregation, delayed resolution, or strategic routing, and cannot be reduced without loss of essential structure.

**Privacy wall.** A privacy wall is an informational boundary created by Non-Myerson Layers across which actions and outcomes are observable, but underlying motivations cannot be uniquely inferred. Privacy walls preserve ambiguity of intent by permitting non-scalar variables to motivate action and prevent agents from conditioning strategies outside the mechanism on fully reconstructible causal explanations of behavior within it.

**Circular mechanism.** A circular mechanism is a mechanism whose outputs re-enter itself as inputs in future stages of play, so that agents' present actions shape the future strategic environment in which they and others must act. In circular mechanisms, learning and revision are endogenous, and incentive compatibility depends on how the mechanism disciplines attempts to revisit or unwind past decisions.

**Risk.** Risk refers to uncertainty over a fully specified and stable set of possible states, where the mapping from actions to outcomes is known and probabilities can be meaningfully assigned *ex ante*. Under risk, agents can evaluate strategies by computing expected utilities, price deviations in advance, and revise behavior through belief updating without incurring structural costs beyond those implied by known distributions.

**Knightian uncertainty.** Knightian uncertainty refers to uncertainty over states, variables, or aggregation outcomes that are not defined



at the time action must be taken, and therefore cannot be assigned probabilities *ex ante*.

**Unactionability.** A constraint is unactionable if agents cannot condition their behavior so as to offset, unwind, or neutralize its effects within the mechanism, even when the constraint is observed or anticipated.

**Endogenous unactionability.** A constraint is endogenously unactionable if it is generated by strategic interaction within the mechanism and, once generated, cannot be neutralized, offset, or unwound by further strategic action within that same mechanism.

**Informational decentralization.** A mechanism is informationally decentralized if no agent or authority has access to the full state required to determine outcomes or enforce behavior at the time actions are taken. Information relevant to outcomes is dispersed across agents and realized only through interaction over time.

## B Circular Mechanisms

This appendix provides a taxonomy of representative circular mechanisms. The purpose is not to be exhaustive, but to illustrate how known families of mechanisms relate to the core distinctions developed in the text.

## C Saito as an Implemented Instance of Endogenous Unactionability

This appendix provides a constructive witness to the claims made in the paper. It does not attempt to prove correctness, security, or equilibrium properties. Rather, it shows how non-reducibility emerges in practice from the structural requirements for incentive compatibility identified in theory.

## C.1 Layers, Aggregation, and Arbitrage

Saito Consensus consists of three Non-Myerson Layers cycling in parallel. Each layer aggregates preferences revealed by others into welfare-improving proposals that adjust global prices. Three cross-layer properties are primitive structural requirements for avoiding impossibility in theory:

- **Continuation value.** Benefits include options for continued play, which are actively traded between participants as part of the aggregation process, dividing transaction fees into mining and routing payouts.
- **Costly uncertainty.** All strategies require participants to commit to front-loaded and irreversible expenditures of utility that are fungible with continuation value (fees, routing rewards, or resource consumption) under uncertainty.
- **Informational decentralization.** No trusted authorities exist in any layer of the mechanism. Players act under uncertainty about the global state, which is dispersed and aggregated only through play over time.

These properties apply to each of the three layers in the mechanism, which are distinguished by their aggregation functions and the arbitrage opportunities they expose.

### User Layer

- *Aggregates:* Heterogeneous bundles of utility into transactions.
- *Arbitrages:* Differences between local execution opportunities and global settlement prices, broadcast as transactions for processing and settlement by other layers.

### Routing Layer

- *Aggregates:* Bundles of transactions into provisional blocks.
- *Arbitrages:* Differences between marginal routing rewards and the cost of providing ancillary collusion goods, producing efficient routing paths for payout division.

## Chain Resolution Layer

- *Aggregates*: Bundles of blocks into chains with a cost of revision.
- *Arbitrages*: Discrepancies between current aggregate security preferences and expected future settlement conditions, broadcast as payouts that simultaneously propose adjustments to global prices.

Each layer acts both as an aggregator of upstream preferences and as a generator of downstream arbitrage opportunities. No layer determines final meaning in isolation. Convergence is emergent, and the cost of revision increases with block settlement depth in the game tree.

## C.2 Trust, Uncertainty, and Exposure

Trust is a semantically meaningless variable. It is measured only indirectly, through the shifts it induces from reliance on mechanism-enforced collective settlement guarantees to coordination through private channels where counterparty credibility is subject to time inconsistency.

These shifts take the form of selective disclosure strategies that pierce the privacy walls of the mechanism. Where such strategies are rational, they improve public welfare by optimizing the enforcement function. Where they are irrational, they reduce the expected utility of the proposer.

### User Layer

- Selective disclosure of preference maps to routers.

### Routing Layer

- Selective disclosure of preference maps to users.
- Selective disclosure of routing competitiveness to peers.

### Chain Resolution Layer

- Selective disclosure of willingness to bear future exposure.

All forms of selective disclosure become less rational as the marginal utility of environmental trust converges toward equilibrium with the marginal utility of the mechanism’s enforcement function.

### **C.3 Non-Reducibility under the Revelation Principle**

The mechanism is a three-layer construct composed entirely of Non-Myerson Layers, and cannot be reduced to a revelation-equivalent mechanism. Messages are shared through public channels only as non-scalar values. Multiple strategies block reduction.

#### **User Layer**

- Routing strategies (Renou & Tomala).
- Selective disclosure (Attar).

#### **Routing Layer**

- Routing strategies (Renou & Tomala).
- Selective disclosure (Attar).

#### **Chain Resolution Layer**

- Routing strategies (Renou & Tomala).
- Selective disclosure (Attar).
- Time-uncertain fixed-difficulty hashing lottery (Strack & Mora).

Across layers, selective disclosure introduces additional Non-Myerson Layers that observe mechanism outputs and produce non-scalar outputs reflecting the attractiveness of coordination outside the mechanism’s enforcement guarantees.

No portion of the mechanism is reducible to a direct mechanism:

- No layer relies on truthful type reports.
- All layers operate concurrently rather than sequentially.

- Information flows are non-stationary and non-topologizable.
- Actions project ambiguous signals rather than verifiable messages.
- Some strategies skip layers through uncertain execution order.
- Learning cannot model semantically undefined variables.

Attempts to analyze any single layer in isolation assume away the exogenous structure provided by the construct as a whole, reintroducing verifiability only by destroying the opacity that allows the mechanism to observe rational responses to the marginal utility of enforcement.

Because all forms of value are fungible with continuation value, higher-dimensional optimization emerges over message spaces containing utilities that can be exchanged for continuation value. These trades aggregate into global prices, inducing convergence.

#### C.4 What This Appendix Does Not Claim

This appendix does not claim:

- that Saito is unique;
- that similar mechanisms are easy to design; or
- that the theory provides a general construction algorithm.

It makes a narrower and stronger observation: *a mechanism satisfying the theoretical constraints identified through implementation theory does exist*, and when other incentive-compatible mechanisms are discovered, they will exhibit the same structural properties.

## D Interpretive Constraints and Irreducible Structure

This paper deliberately avoids equilibrium characterizations and toy models that represent trust, credibility, or willingness to bear exposure as actionable parameters. Any such formalization would reenact the collapse it diagnoses: decisive variables would become conditionable

within the meta-theory, reintroducing the gravity well of revelation-equivalent mechanisms that these constructions are designed to escape. The argument therefore proceeds through structural contradiction, historical diagnosis of impossibility results, and constructive witness rather than internal equilibrium proofs. This is a methodological boundary, not an absence of rigor.

### D.1 Irreducibility and Forbidden Reductions

The mechanisms studied in this paper are intentionally *non-revelation-equivalent*. Any analytical move that presupposes the applicability of the Revelation Principle — including reduction to direct mechanisms, representation of decisive variables as scalar types, or evaluation under a single enforcement regime — alters the object under study and invalidates conclusions drawn from it.

In particular:

- No agent possesses a type that encodes trust, credibility, or willingness to bear exposure.
- No report or message can truthfully represent preferences over enforcement levels.
- No single enforcement regime governs all strategic interaction.

Analyses that assume otherwise implicitly reintroduce exogenous authority or verifiability and therefore collapse the mechanism into a different class.

### D.2 Non-Scalar Variables and Epistemic Boundaries

Several variables that are decisive for equilibrium selection in these mechanisms are *non-scalar* and intentionally unrepresentable. These include trust, credibility, and continuation value under uncertainty. Their role is not to be measured directly, but to motivate action in ways that cannot be neutralized or arbitrated within the mechanism.

The paper’s central claim is not that such variables are ineffable or psychological, but that any attempt to encode them as types destroys the information they convey. This creates epistemic boundaries — privacy walls — across which actions are observable but intent is not reconstructible. These boundaries are structural, not accidental.

### D.3 Parallel Enforcement Regimes

Selective disclosure strategies operate by shifting coordination into *parallel games* governed by different enforcement regimes. These regimes are not deviations, collusion, or exits from the mechanism, but are induced by its design and feed back into it as structured but opaque signals.

The mechanism does not observe the content of these interactions. It observes only the willingness of agents to bear exposure outside its guarantees. This is sufficient to infer the marginal utility of its own enforcement function.

Any interpretation that treats off-mechanism coordination as exogenous or illicit misses this feedback loop and misidentifies the equilibrium logic.

### D.4 Shiva, Entropy, and Continuation Value

The role played by *Shiva* in this paper should not be understood as that of a discretionary authority, governance body, or punitive enforcer. Shiva denotes the *irreversible sink* required to couple continuation value with real costs over time.

Shiva is external to the mechanism’s strategic domain but internal to the agents’ evaluative horizon. It is not a player, rule, layer, or governance body, and no action within the mechanism can condition on it strategically. Yet agents experience Shiva as time, irreversibility, and loss, and therefore incorporate its effects directly into their private judgments of continuation value. In this sense, Shiva supplies the functional role of authority without being an institutional authority: it constrains behavior by rendering certain choices irreversible, not by issuing commands, verifying actions, or enforcing rules. Because Shiva cannot be manipulated, appealed to, or conditioned upon within the mechanism, it remains authoritative only in the phenomenological sense that its consequences are real to participants and unavoidable over time.

Hashing links two aspects of the same object:

1. *Continuation value*, which agents trade and allocate through strategic interaction.
2. *Entropy expenditure*, which renders certain actions irreversible

and prevents the unwinding of exposure.

These are not separable. Continuation value is only meaningful because it can be irreversibly spent; entropy expenditure is only economically relevant because it destroys continuation value. Framing Shiva as a “high cost” misunderstands its function: it is not a deterrent priced in equilibrium, but the thermodynamic constraint that makes time, commitment, and revision meaningful.

Without such an entropy sink, enforcement collapses into arbitrage, as exposure can always be reversed or postponed. With it, costs are front-loaded under uncertainty and cannot be neutralized by strategic play.

### D.5 Evaluation Criterion

Incentive compatibility in these mechanisms must be evaluated over *histories and parallel games*, not reports. The relevant question is not whether agents can profitably misreport preferences, but whether they can improve expected welfare by manipulating the mechanism’s enforcement function without bearing irreversible exposure.

The paper’s claims apply only under this evaluative frame. Within it, impossibility results derived for direct mechanisms remain correct but incomplete.

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Mechanism	Type	Revelation-Equivalent	Location of Unactionability
VCG, Myerson auctions	Direct	Reducible	Exogenous (verifiability, transfers enforcement assumptions)
One-shot voting games (Arrow, Gibbard–Satterthwaite)	Direct	Reducible	Exogenous (fixed rules, no revision, costless speech)
Repeated direct mechanisms with Bayesian updating	Direct	Reducible	Exogenous (fixed state space, common priors, stationary likelihoods)
Public randomization / correlating mechanisms	Both	Yes	Exogenous (unmanipulable public randomness)
Posted-price mechanisms	Indirect	Reducible	Exogenous (prices set outside the mechanism)
Continuous double auctions	Indirect	Irreducible (mostly)	Mixed; often exogenous via institutional rules, sometimes endogenous via market impact
Reputation systems	Indirect	Irreducible	Endogenous (history-dependent payoffs, difficult to unwind reputational effects)
Contract renegotiation mechanisms	Indirect	Irreducible	Mixed; exogenous when courts enforce, endogenous when renegotiation costs persist
Prediction markets with endogenous liquidity	Indirect	Irreducible	Endogenous (liquidity and price impact respond to participation but are not fully controllable)
Gossip-based broadcast and coordination protocols	Indirect	Irreducible	Exogenous or Mixed (scheduler assumptions, network topology)
Proof-of-Work consensus	Indirect	Irreducible	Endogenous (irreversible expenditure of hash)
Proof-of-Stake slashing	Indirect	Irreducible	Mixed; Endogenous w/ Governance
Saito Consensus	Indirect	Irreducible	Endogenous (irreversible loss of continuation value)

**Table 1.** A taxonomy of circular mechanisms and the location of unactionability.