(In)Stability in Networked Markets

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Abstract

Networked markets rely on infrastructure whose operational availability is controlled by market participants. We study a two-sided transferable-utility matching market in which coalitions can profit by withholding links before settlement, changing outsiders' feasible trades and the settlement environment—a network disruption externality. A settlement rule assigning a self-enforcing payoff after each withholding event prices the externality and induces a characteristic-function game. Network-stable payoffs are exactly its core; existence is equivalent to Bondareva–Shapley balancedness, and nonexistence occurs when disruption rents create infeasible overlapping claims. Simple local ownership patterns generate nonexistence for an open set of surplus vectors under every settlement rule, and the probability of structural instability converges exponentially to one in large random markets. Finally, the punishment rule characterizes when disruption-neutral settlement is feasible. When it is, balanced-budget transfers convert any settlement rule into one under which the entire fixed-network core is network-stable.

Keywords: Network stability, Endogenous feasibility, Matching markets, Cooperative games with externalities, Strategic link withholding, Access rights, Settlement design

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1. Introduction

Networked markets distinguish physical connectivity from operational availability. Electricity lines, pipeline capacity, and rail routes may exist, yet particular trading connections may be unavailable when trade is cleared and settled. Because market rules cannot prescribe availability in every scenario, agents who control access may change which trades are feasible rather than merely choosing among trades. The difference between "the link exists" and "the link is available" can therefore be the difference between competition and market power.

This paper asks when decentralized trade is stable in a networked market where coalitions can manipulate feasible trades by withholding links. We study a two-sided transferable-utility matching market in which links are subject to access rights. A coalition that controls links can withhold them, thereby inducing a new active network. The market then settles on that induced network. We represent the resulting payoff through a settlement rule and require it to be self-enforcing in the induced fixed-network market. For simplicity, we use electricity markets as our application.

An example illustrates the main economic force. Two generators, g_1 and g_2, can serve a single firm i with unit demand. Matching g_1 with i creates surplus 9, while matching g_2 with i creates surplus 10. A third party t controls the rights to both links. When the full network is available, the efficient match is (g_2, i). The fixed-network core includes payoffs that give i most of the surplus because i has a strong outside option: if underpaid, it can match with g_1 and generate 9. For example, $(u_i, u_{g_1}, u_{g_2}, u_t) = (8, 0, 1, 1)$ is a core payoff when the full network is available.

Now allow link availability to be endogenous. Coalition $\{g_1, t\}$ produces no surplus internally: g_1 cannot match without i, and t is a rights holder who never matches. But if t withholds the link (g_2, i), the induced market contains only the lower-value productive link (g_1, i). The deviation leaves i without an alternative to matching with g_1. Through the subsequent market settlement, there are self-enforcing payoff allocations in which g_1 and t capture most of the remaining surplus, for example, $(\hat{u}_i, \hat{u}_{g_1}, \hat{u}_{g_2}, \hat{u}_t) = (1, 4, 0, 4)$. Thus, a coalition that cannot create surplus by matching can profit by destroying an outsider's feasible alternative. We call this a *network disruption externality*: by changing nonmembers' feasible trades, a deviating coalition changes the settlement environment itself.

The example highlights a conceptual problem. Core stability in the fixed-network market disciplines rematching deviations, but it does not discipline deviations that change the network on which the market settles. When a coalition changes the active network, it alters the feasible opportunities and coalitional values of other players. The canonical way to model such externalities in cooperative game theory is through a partition-function game, where a coalition's worth depends on how the remaining players are organized (Thrall and Lucas, 1963). Core analysis in such games depends on the assumed response of outsiders to a deviation, and different response assumptions generate different core concepts. Consequently, the classical Bondareva–Shapley characterization does not apply directly to the primitive externality environment.

Our first contribution is methodological. We exploit the structure of networked matching markets to reduce this externality problem to a characteristic-function game. Conditional on any active network, we define a *settlement game*: the transferable-utility matching game obtained by holding that network fixed. Every such settlement game has a nonempty core.

A *settlement rule* assigns, to every withholding coalition and every active network it can induce, a core payoff of the corresponding settlement game. The rule thereby prices the externality generated by the coalition's network action. Folding that price into each coalition's worth yields an ordinary transferable-utility characteristic-function game, the *network disruption game*.

The reduction is exact. Theorem 1 establishes that a payoff is *network-stable*—immune both to rematching under the full network and to link-withholding deviations followed by self-enforcing settlement—if and only if it lies in the core of the network disruption game. Network-stable payoffs therefore exist if and only if the network disruption game is balanced in the Bondareva–Shapley sense. Moreover, each coalition's worth decomposes into its fixed-network value and a *disruption rent*, the incremental claim created by its ability to alter the active network. Because the full-network settlement game has a nonempty core, fixed-network coalitional claims are jointly feasible. Nonexistence arises precisely when the disruption rents of a balanced collection of coalitions exceed the slack left by those fixed-network claims.

Our second contribution establishes that nonexistence is robust and can be generated by simple local ownership patterns. We define the *punishment rule*, which selects after each withholding event an induced-core payoff minimizing the deviating coalition's aggregate payoff. This rule produces the largest network-stable set among all settlement rules. Consequently, if the network disruption game is not balanced even under the punishment rule, no settlement rule can support a network-stable payoff.

Using this test, we identify two elementary 2×2 ownership patterns. A *market gate* has four distinct third-party rights holders controlling the four links of the subnetwork. A *concentrated component* has two rights holders partitioning control across its two perfect matchings. Theorem 2 establishes that any network structure containing either pattern is structurally unstable: for a nonempty open set of surplus vectors, no settlement rule supports a network-stable payoff. These patterns are sufficient but not necessary. Structural instability can also arise in a network containing neither pattern, even when every cross-link is controlled by one of its endpoints and no agent controls more than one cross-link. Finally, in our random large-market model, the probability that the market contains a market gate converges to one, and therefore the probability of structural instability converges exponentially to one.

Our third contribution identifies a transparent benchmark for repairing the full-network core through settlement design. A settlement rule is *disruption neutral* if no rights-holding coalition can obtain through withholding more than its full-network coalitional worth. Theorem 3 establishes that under such a rule, every payoff in the full-network core is network-stable. Moreover, any baseline settlement rule can be converted into a disruption-neutral rule through event-contingent transfers that sum to zero across market participants. Disruption neutrality is a sufficient condition for full-core preservation, but not a necessary one: positive disruption rents may leave the full-network core unchanged when they can be absorbed by slack already present in its coalitional constraints.

The punishment rule provides an exact test for whether the disruption-neutrality benchmark is attainable: because it minimizes each deviating coalition's aggregate payoff across self-enforcing settlements of the induced networks, the disruption rents that remain under punishment cannot be eliminated through settlement selection. In particular, the punishment rule is disruption neutral if and only if all such irreducible disruption rents vanish, which holds if and only if some disruption neutral settlement rule exists.

Centralization operates on a different margin. If a single agent controls every cross-link, then a network-stable payoff exists for every surplus vector and every settlement rule. Centralization need not, however, eliminate irreducible disruption rents or preserve every full-network core payoff. Ownership concentration, therefore, guarantees the existence of a particular extremal stable allocation, whereas disruption-neutral settlement provides a transparent and sufficient route for protecting the entire full-network core.

The policy interpretation follows directly. Open-access requirements and centralized operational authority change which withholding deviations are feasible. Monitoring and reporting rules support observability of the withholding coalition and the induced active network. Settlement and market-power-mitigation rules determine how the scarcity created by an induced network is rewarded. The irreducible-rent characterization marks the boundary of what self-enforcing payment design can do to eliminate disruption incentives: when irreducible rents vanish, balanced-budget transfers can implement disruption neutrality; when they are positive, payment redesign alone cannot reduce every coalition's withholding payoff to its full-network worth. Such rents may still be absorbed by existing core slack, but eliminating the underlying disruption incentive may require stronger governance of operational access.

Literature. Our fixed-network benchmark builds on assignment games and matching with transfers, beginning with Shapley and Shubik (1971), and is related to matching with contracts and trading networks. Hatfield and Milgrom (2005) develop a framework in which the feasible contract set is fixed; Ostrovsky (2008) studies chain stability in vertical supply-chain networks; and Hatfield and Kominers (2012), Hatfield et al. (2013) study stability in networks of bilateral contracts.[1] Kamada and Kojima (2015, 2018, 2024) show that exogenous distributional or feasibility constraints can destroy standard stability and require either structural restrictions or weaker solution concepts. These papers take the feasible network, contracts, or constraint structure as fixed once the market is specified. Our paper studies a different problem: coalitions that control access rights can change matching feasibility before market settlement. Thus, the relevant deviations are not only rematchings within a fixed network but also manipulations of feasibility itself.

Link withholding creates an externality across coalitions, the kind of dependence formalized by partition-function games (Thrall and Lucas, 1963). In this literature, the response to a deviation is the key modeling choice: Aumann and Peleg (1960) distinguish alpha- and beta-effectiveness, Chander and Tulkens (1997) constructs a gamma-characteristic function, and Kóczy (2007), Huang and Sjöström (2006) recursively solve residual partition-function games. Our settlement rule is related to these response disciplines but is not identical to them. Conditional on the active network

[1]The utility-representation result in Hatfield and Kominers (2012) is corrected by Hatfield et al. (2020); our use of the paper is only as a fixed-feasibility trading-network benchmark.

induced by withholding, the market must settle at a core allocation of the induced fixed-network game; this self-enforcing settlement prices the externality and yields a transferable-utility characteristic-function game. Work on efficiency and values in partition-function games, such as Hafalir (2007) and de Clippel and Serrano (2008), is therefore adjacent but asks a different question: how to evaluate or divide surplus under externalities, rather than when feasibility manipulation destroys stability.

Our notion of network stability is related to theories of coalitional self-enforcement and farsighted deviation. Online Appendix A compares our model to these frameworks in detail. Bernheim et al. (1987) introduces coalition-proofness as a recursive credibility requirement in noncooperative games, while Ray and Vohra (1997) studies binding agreements in strategic-form games with externalities and emphasizes that the behavior of the complement of a deviating coalition must be modeled explicitly. Chwe (1994), Konishi and Ray (2003), Ray and Vohra (2015) develop farsighted or dynamic notions of coalitional stability, with Ray and Vohra (2015) stressing coalitional sovereignty: a deviating coalition should not freely assign payoffs to outsiders. The closest dynamic counterpart to our approach is Ali and Liu's (2026) perfect coalitional equilibrium, in which history-dependent continuation plans deter coalitional blocking in repeated games.[2] A settlement rule is not a continuation plan. It is a within-period institution that selects a self-enforcing allocation after an active network has been induced. This static reduction is what delivers the network disruption game, the balancedness characterization, and the disruption-rent decomposition.

Our model is also adjacent to biform games, where actions can change the cooperative environment in which the game is subsequently played. In Brandenburger and Stuart (2007), first-stage noncooperative strategic choices shape a second-stage cooperative game; related value-capture work studies how alternative positions determine surplus appropriation (Brandenburger and Stuart Jr, 1996; Gans and Ryall, 2017; MacDonald and Ryall, 2004; Ross, 2018; Ryall and Sorenson, 2007). In our model, link withholding is not a strategic-positioning choice to be solved by a noncooperative equilibrium concept with second-stage cooperative payoffs. It is a coalitional blocking technology. The settlement rule prices each blocking opportunity, and the resulting object is the core of the network disruption game, not an equilibrium.

[2] A related issue arises in applied bargaining models. For instance, Yu and Waehrer (2024) modify Nash-in-Nash bargaining by making disagreement payoffs recursive, so that remaining bilateral negotiations are resolved knowing that a disagreement occurred; their focus, however, is payoff division in interdependent bilateral bargaining, not network stability.

Finally, the concept of a network disruption externality is connected to industrial organization work on foreclosure and bottleneck access. Hart et al. (1990), Ordover et al. (1990), Rey and Tirole (2007) show how control over input access or essential facilities can disadvantage rivals. Electricity markets provide a leading application: transmission rights and congestion can create market power (Borenstein et al., 1997; Bushnell, 1999; Joskow and Tirole, 2000), market-power rents can be large in restructured power markets (Borenstein et al., 2002), and operational unavailability itself can be strategic (Fogelberg and Lazarczyk, 2019). Bushnell et al. (2008) add an important caution: vertical arrangements can mitigate market power when they reduce spot-market exposure. Our contribution is not another electricity-market model. It is a general cooperative stability framework that analyzes when access control creates disruption rents and when settlement design can eliminate them.

Paper organization. Section 2 introduces the networked economy, access rights, active networks, and the link-withholding technology. Section 3 defines the fixed-network settlement game and uses the opening example to show why its core does not discipline network disruption. Section 4 defines network stability and the network disruption game and establishes the representation, balancedness, and disruption-rent decomposition. Section 5 develops the punishment benchmark, the structural-impossibility theorem, the dispersed-rights example, and the large-market result. Section 6 characterizes disruption-neutral settlement and irreducible disruption rents and studies balanced-budget mitigation and centralization. Section 7 relates the results to electricity-market institutions and discusses the scope of the model. Proofs are deferred to the appendix.

2. Model

2.1. Institutional Motivation

Many networked markets distinguish physical infrastructure from operational availability. Electricity transmission lines, pipeline capacity, rail routes, and telecommunications links may exist as assets, but particular connections may be unavailable when trades are cleared because of scheduling, outage claims, maintenance, or access-control rights. Electricity is our leading example, but the model is general: it applies whenever trade is organized over a network, access to links is controlled by identifiable agents, and feasible trade in the relevant window is determined by the active network rather than by the underlying physical network.

We study one clearing-and-settlement window. Before trade is settled, a coalition that controls access rights may withhold links, thereby inducing an active network. Once the active network is determined, the market settles on that network according to the prevailing market arrangements.[3] The resulting matches and transfers apply to the current window. After the window closes, the background infrastructure and access-right ownership remain fixed. Thus, withholding changes the current settlement environment without permanently destroying links or rewriting ownership rights. The model isolates this within-window stability problem from dynamic investment, repeated-game punishments, and long-run regulatory design.

2.2. Primitives

There are finite disjoint sets of generators G, firms I, and pure rights holders P; with typical elements $g \in G$, $i \in I$, and $t \in P$. The set of players is denoted by $N = G \cup I \cup P$. Trade is constrained by a physical network $L = E \cup E^0$, where $E \subseteq G \times I$ is the set of cross-links between generators and firms, and $E^0 = \{(n, n) : n \in G \cup I\}$ is the set of self-links. A cross-link $(g, i) \in E$ means that generator g and firm i are physically connected. A self-link (n, n) represents the possibility that trading agent n remains unmatched.

Each cross-link $e \in E$ is associated with an access right. The holder of that right controls whether e is made available for market-mediated trade during the settlement window. Access rights may be held by generators, firms, or by agents who do not trade in the matching market. Access rights are described by a map $\tau : E \to N$, where $\tau(e)$ is the holder of the right to cross-link e. We assume without loss of generality that every pure rights holder controls at least one cross-link: for every $t \in P$, there exists $e \in E$ such that $\tau(e) = t$.[4] For notational convenience, we extend τ from E to all of L by setting $\tau(n, n) = n$ for every $n \in G \cup I$.

Each link $l \in L$ has a surplus $v_l \in \mathbb{R}$. If $l = (g, i) \in E$, then v_l is the surplus generated when generator g and firm i match. If $l = (n, n) \in E^0$, then v_l is the

[3] We use *settlement* as a reduced-form description of the final matches and transfers for the window, not as an assumption that a distinct player or mediator selects the outcome. Settlement may arise cooperatively through agreement among market participants or noncooperatively through bilateral bargaining, posted prices, an auction, or centralized market clearing. We abstract from the particular protocol and represent only its payoff consequence.

[4] If a pure rights holder controls no cross-link, then they neither affect feasibility nor generate surplus and can be deleted from the economy. If a legal right is exercised by a consortium or designated operator, the model represents the entity as a single player.

surplus obtained when trading agent n remains unmatched. Pure rights holders have no primitive production technology and no unmatched surplus. Holding an access right does not directly create surplus.

A *network structure* is a tuple $\Lambda = (G, I, P, L, \tau)$ satisfying the restrictions above. A *networked economy* is a pair $\mathcal{E} = (\Lambda, v)$, where $v = (v_l)_{l \in L} \in \mathbb{R}^{|L|}$ is the vector of link surpluses. We write $N_{\mathcal{E}}$ for the player set of economy $\mathcal{E}$.

2.3. Link withholding and active networks

Fix a networked economy $\mathcal{E}$. For a coalition $S \subseteq N_{\mathcal{E}}$, let

$$\mathcal{R}_{\mathcal{E}}(S) = \{l \in L : \tau(l) \in S\}$$

denote the set of links controlled by S. An *active network* is any set of links $\hat{L}$ such that $E^0 \subseteq \hat{L} \subseteq L$. Given coalition S, the set of active networks that S can induce by withholding at least one cross-link is:

$$\mathcal{L}_{\mathcal{E}}(S) = \left\{ \hat{L} = L \setminus R : \emptyset \neq R \subseteq \mathcal{R}_{\mathcal{E}}(S) \setminus E^0 \right\}.$$

Thus $\mathcal{L}_{\mathcal{E}}(S)$ excludes the original physical network L: it is the set of networks that can arise from a nontrivial withholding deviation by S.

When S induces $\hat{L}$, the withholding event $(S, \hat{L})$ is publicly observed before trade is settled.[5] The active network is the operative feasibility constraint for all market-mediated trades in that settlement window. A withheld cross-link cannot be used in the induced market, including by the coalition that withheld it.

2.4. Matching feasibility

Fix an economy $\mathcal{E}$, an active network $\hat{L}$, and a coalition $S \subseteq N_{\mathcal{E}}$. Let $S_G = S \cap G$, $S_I = S \cap I$, and $S_{GI} = S \cap (G \cup I)$. A *matching of the trading agents in S* is a function $\mu : S_{GI} \to S_{GI}$ such that:

i. $\mu(g) \in S_I \cup \{g\}$ for every $g \in S_G$;
ii. $\mu(i) \in S_G \cup \{i\}$ for every $i \in S_I$;
iii. for every $g \in S_G$ and $i \in S_I$, $\mu(g) = i$ if and only if $\mu(i) = g$.

[5] In the motivating applications, availability for clearing is typically recorded through operating procedures, outage reports, nominations, releases, curtailment instructions, or other settlement-relevant submissions. We use the public observability of $(S, \hat{L})$ as the perfect-monitoring benchmark for the withholding event.

Thus, each generator is matched with at most one firm, each firm is matched with at most one generator, and $\mu(n) = n$ means that trading agent n remains unmatched. The *link representation* of matching μ in S is

$$M_\mu(S) = \{(g,i) : g \in S_G,\ i \in S_I,\ \mu(g) = i\} \cup \{(n,n) : n \in S_{GI},\ \mu(n) = n\}.$$

A matching and its link representation uniquely determine one another: each trading agent appears in exactly one link of $M_\mu(S)$.[6] We therefore identify a matching with its link representation when evaluating feasibility and surplus.

A matching is feasible for coalition S on active network $\hat{L}$ if every link in its link representation is active and controlled by S. Accordingly, the set of feasible matchings, represented as link sets, is

$$\mathcal{M}_{\mathcal{E},\hat{L}}(S) = \left\{ M_\mu(S) : \mu \text{ is a matching of } S_{GI} \text{ and } M_\mu(S) \subseteq \hat{L} \cap \mathcal{R}_{\mathcal{E}}(S) \right\}.$$

This set is nonempty: the matching defined by $\mu(n) = n$ for every $n \in S_{GI}$ is feasible; when $S_{GI} = \emptyset$, it is the empty matching. For any $M \in \mathcal{M}_{\mathcal{E},\hat{L}}(S)$, its surplus is $v(M) = \sum_{l \in M} v_l$, with the convention that the empty sum is zero.

3. Fixed-Network Settlement and Network Disruption

3.1. The Settlement Game

We first define the cooperative game that would be analyzed if the active network were fixed. This is the fixed-feasibility benchmark: coalitions may rearrange matches and transfers, but they take the active network as given. We define the game on an arbitrary active network because withholding will later induce a settlement stage in which such a game is played on the relevant active network.

Fix an economy $\mathcal{E}$ and an active network $\hat{L}$. The *settlement game* on $\hat{L}$ is the transferable-utility cooperative game $\Gamma(\mathcal{E}, \hat{L}) = (N_{\mathcal{E}}, V_{\mathcal{E},\hat{L}})$, where for each coalition $S \subseteq N_{\mathcal{E}}$,

$$V_{\mathcal{E},\hat{L}}(S) = \max_{M \in \mathcal{M}_{\mathcal{E},\hat{L}}(S)} v(M).$$

The value $V_{\mathcal{E},\hat{L}}(S)$ is the maximum surplus coalition S can generate by matching internally, using only links that are active under $\hat{L}$ and controlled by S. Since $\mathcal{M}_{\mathcal{E},\hat{L}}(S)$

[6] A self-link uniquely identifies an unmatched agent, while a cross-link (g,i) uniquely identifies the assignments $\mu(g) = i$ and $\mu(i) = g$.

is nonempty for every S, $V_{\mathcal{E},\hat{L}}$ is well defined. The core of the settlement game is

$$Core(\Gamma(\mathcal{E},\hat{L})) = \Big\{ u \in \mathbb{R}^{N_{\mathcal{E}}} : \sum_{n \in N_{\mathcal{E}}} u_n = V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}}), \\ \sum_{n \in S} u_n \geq V_{\mathcal{E},\hat{L}}(S) \quad \text{for every } S \subseteq N_{\mathcal{E}} \Big\}. \tag{1}$$

A settlement-core payoff is efficient for the active network and immune to every coalitional rematching deviation within the fixed active network.

Lemma 1 (Nonemptiness of the settlement core)**.** *For every economy $\mathcal{E}$ and every active network $\hat{L}$, $Core(\Gamma(\mathcal{E},\hat{L})) \neq \emptyset$.*

The proof adapts the linear-programming duality argument of the assignment game from Shapley and Shubik (1971). Conditional on $\hat{L}$, ignoring access-right restrictions yields a two-sided transferable-utility matching game between generators and firms, with self-links representing unmatched agents and trade restricted to active links. Adapting the assignment-game argument, we show that this outer game has a nonempty core. Extending any outer-core payoff by assigning zero to pure rights holders then yields a core payoff of $\Gamma(\mathcal{E},\hat{L})$, because requiring the relevant access-right holder to belong to a coalition can only reduce what that coalition can achieve.

3.2. A Network Disruption Externality

The settlement game rules out profitable rematching while the active network is fixed. However, it does not rule out deviations that change the active network before settlement. The example from the introduction shows the distinction.

Let $G = \{g_1, g_2\}$, $I = \{i\}$, and $P = \{t\}$. The cross-links are $E = \{(g_1, i), (g_2, i)\}$, both controlled by t: $\tau(g_1, i) = \tau(g_2, i) = t$. Match surplus is $v_{(g_1,i)} = 9$ and $v_{(g_2,i)} = 10$, and all self-link surpluses are zero. Under the full network L, the settlement game has characteristic function

$$V_{\mathcal{E},L}(S) = \begin{cases} 10, & \text{if } \{g_2, i, t\} \subseteq S, \\ 9, & \text{if } \{g_1, i, t\} \subseteq S \text{ and } \{g_2, i, t\} \nsubseteq S, \\ 0, & \text{otherwise.} \end{cases}$$

The payoff vector u given by $u_i = 8$, $u_t = 1$, $u_{g_2} = 1$, and $u_{g_1} = 0$ belongs to $Core(\Gamma(\mathcal{E}, L))$: efficiency holds because total payoff is 10, and, apart from efficiency, the nonzero coalitional constraints are satisfied:

$$u_{g_2} + u_i + u_t = 10 \quad \text{and} \quad u_{g_1} + u_i + u_t = 9.$$

Thus u is stable against all rematching deviations when the full network is held fixed.

Now let coalition $\{g_1, t\}$ withhold cross-link (g_2, i), inducing $\hat{L} = L \setminus \{(g_2, i)\}$. The induced settlement game has characteristic function

$$V_{\mathcal{E},\hat{L}}(S) = \begin{cases} 9, & \text{if } \{g_1, i, t\} \subseteq S, \\ 0, & \text{otherwise.} \end{cases}$$

The payoff vector $\hat{u}$ with $\hat{u}_i = 1$, $\hat{u}_{g_1} = 4$, $\hat{u}_t = 4$, and $\hat{u}_{g_2} = 0$ belongs to $Core(\Gamma(\mathcal{E}, \hat{L}))$: it is efficient and satisfies the only nonzero coalitional constraint, $\hat{u}_{g_1} + \hat{u}_i + \hat{u}_t = 9$. Moreover, if $\{g_1, t\}$ anticipates $\hat{u}$, the withholding deviation is profitable for $\{g_1, t\}$ relative to u, since $\hat{u}_{g_1} + \hat{u}_t = 8 > 1 = u_{g_1} + u_t$.

In this case, the coalition does not profit by rematching internally under the full network; without firm i, it cannot produce any matching surplus. Instead, it profits by changing the settlement environment. Withholding (g_2, i) removes the constraint generated by coalition $\{g_2, i, t\}$ and lowers the outside option of firm i in the induced market. We call this a *network disruption externality*: by changing which links are active, a coalition alters the fixed-network settlement game that will be played.

For this particular induced settlement $\hat{u}$, any full-network core payoff with $u_{g_1} + u_t < 8$ is vulnerable to the same withholding deviation. Since full-network core payoffs satisfy $u_{g_1} = 0$, immunity to this deviation-settlement pair requires $u_t \geq 8$. Thus, even in this simple economy, fixed-network core stability is not the same as stability against network disruption. The next section formalizes this observation by specifying how induced settlement payoffs are selected after each observable withholding event.

4. Network Stability and the Network Disruption Game

4.1. Settlement rules

We now formalize the payoff consequences of settling after link withholding. While a coalition can deviate by rematching while the full network remains active, it can also withhold controlled cross-links, induce a new active network, and then participate in the settlement of the market on that network. A settlement rule records the final payoff vector produced after each observable withholding event.

Define the set of coalitions that can induce a nontrivial active network by

$$\mathcal{S}_{\mathcal{E}}^{R} = \{S \subseteq N_{\mathcal{E}} : \mathcal{L}_{\mathcal{E}}(S) \neq \emptyset\}.$$

A coalition belongs to $\mathcal{S}_{\mathcal{E}}^{R}$ if and only if it controls at least one cross-link.

Definition 1 (Settlement rule)**.** Fix an economy $\mathcal{E}$. A *self-enforcing settlement rule* for $\mathcal{E}$ is a function:

$$\sigma : \{(S, \hat{L}) : S \in \mathcal{S}_{\mathcal{E}}^{R},\ \hat{L} \in \mathcal{L}_{\mathcal{E}}(S)\} \to \mathbb{R}^{N_{\mathcal{E}}},$$

such that:

$$\sigma(S, \hat{L}) \in Core(\Gamma(\mathcal{E}, \hat{L})) \quad \text{for every } S \in \mathcal{S}_{\mathcal{E}}^{R} \text{ and every } \hat{L} \in \mathcal{L}_{\mathcal{E}}(S).$$

The dependence on both S and $\hat{L}$ reflects the observability of the withholding event. The core restriction formalizes self-enforcement in the induced fixed-network market. It does not require that a planner or mediator choose the payoff vector: σ may summarize the outcome of any cooperative or noncooperative settlement process. The restriction requires only that, once $\hat{L}$ is fixed, no coalition can obtain a larger aggregate payoff by rematching and reallocating transfers within that active network. Otherwise, the selected payoff would be vulnerable to immediate renegotiation and would not constitute a terminal settlement. Because we only consider self-enforcing settlement rules throughout the paper, we will refer to them more simply as "settlement rules."[7]

For each $S \in \mathcal{S}_{\mathcal{E}}^{R}$, define the best aggregate payoff that S can obtain by withholding links under settlement rule σ as

$$B_{\mathcal{E},\sigma}(S) = \max_{\hat{L} \in \mathcal{L}_{\mathcal{E}}(S)} \sum_{n \in S} \sigma_n(S, \hat{L}).$$

The maximum is well defined because $\mathcal{L}_{\mathcal{E}}(S)$ is finite and nonempty for every $S \in \mathcal{S}_{\mathcal{E}}^{R}$.

[7] One could imagine weakening the definition of a settlement rule. For instance, a settlement rule could be restricted to depend only on the induced network $\hat{L}$ (omitting S), or agents might have distinct beliefs about which settlement rule would be implemented following withholding. Either interpretation would restrict the discipline a settlement rule could place on a coalition's temptation to withhold links, thereby *reducing* the achievable set of stable payoffs. Our modeling choices therefore further highlight our subsequent instability results.

4.2. σ-network stability

A payoff vector is network-stable if it is immune to both deviation technologies: rematching under the full network and link withholding followed by settlement on the induced active network.

Definition 2 (σ-network stability)**.** Fix an economy $\mathcal{E}$ and associated settlement rule σ. A payoff vector $u \in \mathbb{R}^{N_\mathcal{E}}$ is *σ-network stable* if the following hold:

i. *Intra-network stability:* $u \in Core(\Gamma(\mathcal{E}, L))$;

ii. *Inter-network stability:* $\sum_{n \in S} u_n \geq B_{\mathcal{E},\sigma}(S)$ for every $S \in \mathcal{S}^R_\mathcal{E}$.

We denote the set of σ-network stable payoffs by $NS(\mathcal{E}, \sigma)$.

Intra-network stability requires the payoff vector to lie in the core of the full-network settlement game: no coalition can increase its aggregate payoff by rematching and reallocating transfers while the full network remains fixed. Inter-network stability adds the feasibility-manipulation constraints: no coalition that controls cross-links can obtain a larger aggregate payoff by inducing a different active network and then settling according to σ.

The definition treats the terminal observable withholding event as the unit of analysis. If several agents or subcoalitions coordinate multiple withholding actions before settlement, we represent them by the composite event $(S, \hat{L})$, where S is the union of the participants and $\hat{L}$ is the resulting active network.[8] The profitability of the composite deviation is then evaluated for coalition S under the settlement payoff $\sigma(S, \hat{L})$, exactly as in condition (ii). This aggregation covers coordinated withholding actions within the settlement window; the model does not specify a sequential game among independently deviating coalitions or a protocol for interim bargaining before the terminal event.

4.3. The network disruption game

The two deviation technologies can be encoded in a single transferable-utility game. The key insight is to define, for each coalition, its worth as the best payoff it can secure either by rematching under the full network or, if it controls cross-links, by withholding links and settling on the induced active network.

[8] Formally, let $S_1, \ldots, S_J \subseteq N_\mathcal{E}$ and let $R_j \subseteq \mathcal{R}_\mathcal{E}(S_j) \setminus E^0$ be the links withheld by group S_j. If $R = \bigcup_{j=1}^J R_j \neq \emptyset$ and $S = \bigcup_{j=1}^J S_j$, then $R \subseteq \mathcal{R}_\mathcal{E}(S) \setminus E^0$, and therefore $\hat{L} = L \setminus R \in \mathcal{L}_\mathcal{E}(S)$.

Formally, fix an economy $\mathcal{E}$ and associated settlement rule σ. The *network disruption game* is the cooperative game $\Psi(\mathcal{E},\sigma) = (N_{\mathcal{E}}, U_{\mathcal{E},\sigma})$, where for each coalition $S \subseteq N_{\mathcal{E}}$,

$$U_{\mathcal{E},\sigma}(S) = \begin{cases} V_{\mathcal{E},L}(S), & \text{if } S \notin \mathcal{S}^R_{\mathcal{E}}, \\ \max\{V_{\mathcal{E},L}(S), B_{\mathcal{E},\sigma}(S)\}, & \text{if } S \in \mathcal{S}^R_{\mathcal{E}}. \end{cases}$$

Thus, once σ is fixed, every coalition has a scalar worth. The network disruption game is an ordinary characteristic-function game, even though the underlying withholding technology creates externalities across coalitions by changing the active network.

The core of the network disruption game, denoted by $Core(\Psi(\mathcal{E},\sigma))$, is defined by replacing $V_{\mathcal{E},\hat{L}}$ with $U_{\mathcal{E},\sigma}$ in the definition of the core of the settlement game, given in Equation 1.

At the aggregate level, link withholding cannot increase total surplus. Because withholding only removes feasible links, the grand coalition's value in the network disruption game equals the maximum surplus attainable under the full network, that is, $U_{\mathcal{E},\sigma}(N_{\mathcal{E}}) = V_{\mathcal{E},L}(N_{\mathcal{E}})$.[9]

Withholding may nevertheless increase the worth of particular coalitions by changing the claims they can make on the available surplus. The characteristic function of the network disruption game admits a useful decomposition. Define the *disruption rent* of coalition S under σ by

$$\Delta_{\mathcal{E},\sigma}(S) = U_{\mathcal{E},\sigma}(S) - V_{\mathcal{E},L}(S).$$

The disruption rent is the incremental coalitional claim generated by the ability to change the active network and forcibly invoke the settlement rule.

4.4. Representation and characterization of the σ-network stable set

A nonnegative weighting scheme δ on nonempty proper coalitions is *balanced* if

$$\sum_{\substack{\emptyset \neq S \subsetneq N_{\mathcal{E}} \\ n \in S}} \delta(S) = 1 \quad \text{for every } n \in N_{\mathcal{E}}.$$

Theorem 1 (Representation, balancedness, and decomposition)**.** *Fix an economy $\mathcal{E}$ and associated settlement rule σ. Then:*

[9] Any matching feasible after links are withheld is also feasible under the full network. Withholding therefore weakly reduces the grand coalition's feasible matching set and cannot increase its maximum attainable surplus. The identity is established formally in the proof of Theorem 1.

i. $NS(\mathcal{E},\sigma) = Core(\Psi(\mathcal{E},\sigma))$.

ii. $NS(\mathcal{E},\sigma) \neq \emptyset$ *if and only if the network disruption game is balanced, that is, for every balanced weighting scheme* δ *on proper coalitions,*

$$\sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) U_{\mathcal{E},\sigma}(S) \leq U_{\mathcal{E},\sigma}(N_{\mathcal{E}}).$$

iii. $NS(\mathcal{E},\sigma) \neq \emptyset$ *if and only if for every balanced weighting scheme* δ *on proper coalitions,*

$$\sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) \Delta_{\mathcal{E},\sigma}(S) \ \leq \ V_{\mathcal{E},L}(N_{\mathcal{E}}) - \sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) V_{\mathcal{E},L}(S).$$

Part (i) is our representation. After a settlement rule is fixed, network stability is exactly ordinary core stability in the network disruption game. The intra-network and inter-network stability conditions are not separate requirements: together they are exactly the efficiency and coalitional constraints defining $Core(\Psi(\mathcal{E},\sigma))$.

Part (ii) applies the Bondareva–Shapley theorem (Bondareva, 1963; Shapley, 1965). Since $NS(\mathcal{E},\sigma)$ is the core of $\Psi(\mathcal{E},\sigma)$, existence of network-stable payoffs is equivalent to balancedness of the network disruption game. Balancedness asks whether the coalitional claims generated by $U_{\mathcal{E},\sigma}$ can be jointly honored when overlapping coalitions are weighted so that each agent acts exactly once on average.

Part (iii) rewrites the balancedness condition using $U_{\mathcal{E},\sigma} = V_{\mathcal{E},L} + \Delta_{\mathcal{E},\sigma}$ and $U_{\mathcal{E},\sigma}(N_{\mathcal{E}}) = V_{\mathcal{E},L}(N_{\mathcal{E}})$. The right-hand side is the slack left by the full-network settlement game after the fixed-network coalitional claims are aggregated according to δ. This slack is nonnegative because $Core(\Gamma(\mathcal{E},L)) \neq \emptyset$ implies that the fixed-network settlement game is balanced. The left-hand side is the corresponding balanced aggregation of disruption rents. Thus, the decomposition separates ordinary rematching pressure from the extra claims created by link withholding.

4.5. Disruption rents and the source of nonexistence

The decomposition in Theorem 1 identifies where nonexistence might arise. The full-network settlement game always has a nonempty core, so the fixed-network coalitional claims $V_{\mathcal{E},L}(S)$ are jointly feasible. If $NS(\mathcal{E},\sigma)$ is empty, some balanced family of coalitions must generate disruption rents that exceed the slack left by those fixed-network claims.

This is the formal sense in which network instability is caused by link withholding rather than by ordinary matching incentives. A coalition's disruption rent is positive only when the settlement rule allows the coalition to obtain more by changing the active network than by rematching internally under the full network. Balancedness then asks whether all such additional claims can be accommodated simultaneously. When they cannot, no payoff vector can be both a full-network core payoff and immune to all link-withholding deviations.

The disruption-rent decomposition is also useful because it isolates the object that will generate our impossibility results. In the following section, we show that some ownership and network structures generate disruption rents that no settlement rule can eliminate. Our subsequent mitigation results provide an avenue for settlement design to reduce these rents enough to preserve the fixed-network core.

5. Structural Instability

5.1. The punishment benchmark

The preceding characterization reduces existence to balancedness of the network disruption game, given a fixed settlement rule. We introduce a benchmark settlement rule that gives a conservative test for whether stability can be supported by any settlement rule.

Fix an economy $\mathcal{E}$. The *punishment rule*, denoted by σ^P, selects after each withholding event a core allocation of the induced settlement game that minimizes the deviating coalition's aggregate payoff:

$$\sigma^P(S, \hat{L}) \in \underset{u \in Core(\Gamma(\mathcal{E}, \hat{L}))}{\arg\min} \sum_{n \in S} u_n, \quad S \in \mathcal{S}^R_{\mathcal{E}}, \quad \hat{L} \in \mathcal{L}_{\mathcal{E}}(S).$$

When the argmin is set-valued, fix an arbitrary tie-breaking rule. Since deviations are evaluated by the sum of the coalition's payoff, all tie-breaking rules have the same implications. The minimum is attained because the settlement core is a nonempty compact polytope and the objective is continuous.

The punishment rule is not meant to describe a literal market institution. It is a benchmark that makes every withholding deviation as unattractive as possible, subject to the requirement that the induced settlement remain self-enforcing. Therefore, if stability fails under σ^P, then instability cannot be attributed to the choice of the settlement rule.

Proposition 1 (Maximal network-stable set)**.** *For every economy $\mathcal{E}$ and every associated settlement rule σ,*

$$NS(\mathcal{E}, \sigma) \subseteq NS(\mathcal{E}, \sigma^P).$$

For every withholding coalition and every active network it can induce, σ^P gives that coalition the least aggregate payoff among all self-enforcing induced settlements. Hence every inter-network stability constraint under σ^P is weakly easier to satisfy than the corresponding constraint under any other settlement rule. Then, Theorem 1 and Proposition 1 immediately imply that the punishment rule is a conservative screening device. It identifies cases in which no self-enforcing way of settling induced markets can support network-stable payoffs.

Corollary 1 (Punishment test)**.** *Fix an economy $\mathcal{E}$. If $\Psi(\mathcal{E}, \sigma^P)$ is not balanced, then $NS(\mathcal{E}, \sigma) = \emptyset$ for every settlement rule σ.*

5.2. Market gates and concentrated components

We next identify two ownership patterns that generate instability for an open set of surplus vectors. Both patterns are local: they require only a fully connected 2×2 subnetwork.

Definition 3 (Market gate)**.** A network structure $\Lambda = (G, I, P, L, \tau)$ features a *market gate* if there exist distinct generators $g_1, g_2 \in G$, distinct firms $i_1, i_2 \in I$, and distinct pure rights holders $t_{11}, t_{12}, t_{21}, t_{22} \in P$ such that

$$\{g_1, g_2\} \times \{i_1, i_2\} \subseteq E$$

and

$$\tau(g_j, i_k) = t_{jk} \quad \text{for all } (j, k) \in \{1, 2\}^2.$$

A market gate allows targeted isolation. By jointly withholding the two links incident to one trading agent, a coalition can remove that agent's access to the other side of the market. The induced settlement may then give the remaining rival a high payoff floor, creating disruption rents that overlap across coalitions.

Definition 4 (Concentrated component)**.** A network structure $\Lambda = (G, I, P, L, \tau)$ features a *concentrated component* if there exist distinct generators $g_1, g_2 \in G$, distinct firms $i_1, i_2 \in I$, and distinct pure rights holders $t_1, t_2 \in P$ such that

$$\{g_1, g_2\} \times \{i_1, i_2\} \subseteq E$$

and

$$\tau(g_1, i_1) = \tau(g_2, i_2) = t_1 \quad \text{and} \quad \tau(g_1, i_2) = \tau(g_2, i_1) = t_2.$$

A concentrated component allows pivotality. By withholding the links in one perfect matching of the 2×2 subnetwork, a coalition can leave only the links held by the other rights holder active. The remaining rights holder then becomes essential for all positive trade in the induced submarket.

A network component is structurally unstable when it is a component of economies that have empty network stable sets for *any* settlement rule:

Definition 5 (Structurally unstable)**.** A network structure Λ is *structurally unstable* if there exists a nonempty open set $\mathcal{O}_\Lambda \subseteq \mathbb{R}^L$ such that, for every $v \in \mathcal{O}_\Lambda$ and every settlement rule σ for the economy $\mathcal{E} = (\Lambda, v)$,

$$NS(\mathcal{E}, \sigma) = \emptyset.$$

Our notion of structural instability has the demanding requirement that nonexistence persists under small perturbations of the surplus vector.

Theorem 2 (Structural instability)**.** *If a network structure Λ features a market gate or a concentrated component, then Λ is structurally unstable.*

The proof of Theorem 2 uses Corollary 1. For each component, we choose surplus values on the four links of the component so that the network disruption game under punishment violates balancedness with strict inequality. The strict violation persists for all surplus vectors in an open neighborhood of the constructed surplus vector.

Intuitively, the theorem goes beyond a simple failure of balancedness. Withholding changes which agents are indispensable in the induced settlement. A market gate creates this dependence through targeted isolation, while a concentrated component creates it through pivotality. In either case, self-enforcement places lower bounds on the payoffs of different, overlapping coalitions. Each lower bound can be honored in the particular active network that generates it, but the collection of bounds cannot be honored simultaneously via the surplus available under the full network. The balancedness violation reflects this incompatibility among self-enforcing post-withholding claims.

Theorem 2 identifies two transparent ownership patterns that are sufficient for structural instability but does not characterize the full class of structurally unstable network structures. Online Appendix B constructs a structurally unstable network containing neither a market gate nor a concentrated component. In the example, there are no pure rights holders; every cross-link has unit surplus and is controlled by one of its endpoints, and no agent controls more than one cross-link. Nevertheless, link withholding generates claims that are jointly infeasible, implying a strict balancedness violation.

5.3. Large markets

The local nature of Theorem 2 has a large-market implication. Consider the following random network structure. There are ω generators and ω firms. Each potential generator–firm cross-link is present independently with probability $p \in (0, 1]$. There are ω^2 potential pure rights holders in addition to the 2ω trading agents. Conditional on a cross-link being present, its rights holder is drawn independently and uniformly from these $\omega^2 + 2\omega$ potential holders. Pure rights holders who receive no realized link are removed from the final network structure.

Proposition 2 (Large-market instability)**.** *Let Λ_ω be drawn from the random network structure above with fixed $p \in (0, 1]$. There exists a constant $\kappa_p > 0$ such that*

$$\Pr(\Lambda_\omega \textit{ is structurally unstable}) = 1 - O(e^{-\kappa_p \omega}).$$

Proposition 2 implies that the probability that a random network structure is structurally unstable converges exponentially to one as the number of trading agents grows. The proof uses only market gates. We partition the market into $\lfloor \omega/2 \rfloor$ vertex-disjoint 2×2 candidate submarkets. Each candidate is a market gate with probability bounded away from zero for all sufficiently large ω: all four links must exist, and their access rights must be assigned to four distinct pure rights holders. Because the candidate submarkets use disjoint links and all link-existence and ownership draws are independent, the probability that none contains a market gate decays exponentially.[10]

[10]We note that the exact probability distribution over cross-links and rights is not important. Indeed, a similar result could be obtained under the weaker condition that the involved probabilities are bounded away from 0 and independent.

6. Settlement Design and Remediability

The previous section identifies network structures for which disruption rents can eliminate stability under every settlement rule. We now ask a complementary question: when can settlement design eliminate disruption incentives without leaving the class of self-enforcing induced settlements? We next study when settlement design can preserve the entire fixed-network core as network-stable.

6.1. Disruption-neutrality

A settlement rule is disruption neutral if no rights-holding coalition can withhold links to obtain more than it can already secure by rematching under the full network.

Definition 6 (Disruption-neutral settlement)**.** Fix an economy $\mathcal{E}$. A settlement rule σ is disruption neutral if

$$B_{\mathcal{E},\sigma}(S) \leq V_{\mathcal{E},L}(S) \quad \text{for every } S \in \mathcal{S}^R_{\mathcal{E}}.$$

Disruption neutrality restricts how withholding is rewarded under the settlement rule: a coalition may change the active network, but upon doing so, that coalition cannot receive an aggregate payoff above its full-network coalitional worth. As such, disruption neutrality implies that the disruption rent of every rights-holding coalition is equal to zero. Importantly, there may be no disruption neutral settlement rule for an economy $\mathcal{E}$. For instance, Theorem 2 shows that any network structure with a market gate (or concentrated component) fails to have a disruption neutral settlement rule for some open set of surplus vectors.

The key question is whether a disruption-neutral rule exists, which we answer via the punishment rule, as before. Recall that σ^P minimizes the aggregate payoff of the deviating coalition among all core allocations of the induced settlement game. Then, $\Delta_{\mathcal{E},\sigma^P}(S)$ represents the maximum possible gain from disruption that coalition S can induce. The quantity $\Delta_{\mathcal{E},\sigma^P}(S)$ is the portion of the coalition's disruption rent that cannot be removed while preserving self-enforcement in the induced settlement game.

We summarize this chain of reasoning in Lemma 2.

Lemma 2 (Irreducible rents and disruption-neutrality)**.** *For any economy $\mathcal{E}$, the following are equivalent:*

i. The punishment rule σ^P is disruption neutral.

ii. $\Delta_{\mathcal{E},\sigma^P}(S) = 0$ *for every coalition* $S \in S^R_{\mathcal{E}}$.

iii. *There exists a settlement rule* σ *that is disruption neutral.*

This lemma gives the exact boundary for disruption-neutral settlement. If every disruption rent vanishes under punishment, then there is a self-enforcing way to settle every induced network without rewarding any withholding coalition above its full-network worth. If $\Delta_{\mathcal{E},\sigma^P}(S) > 0$ for some coalition S, then some withholding event gives S more than its full-network worth even under the least favorable self-enforcing induced settlement. No settlement rule can eliminate that rent. This precludes disruption neutrality, although it does not by itself imply nonexistence or failure of full-core preservation.

The focus on irreducible rents is useful even in simple examples. In Section 3.2, coalition $\{g_1, t\}$ can profit from withholding (g_2, i) under some induced settlements. However, that deviation is not irreducible: in the induced network, a core allocation can assign the full surplus to firm i, leaving $\{g_1, t\}$ with zero, which is exactly its full-network worth. The example therefore illustrates a governable disruption rent. By contrast, the structural impossibility results above identify environments in which disruption rents survive even under maximal punishment.

6.2. Balanced-budget implementation

Lemma 2 characterizes when disruption-neutral settlement is feasible. We now provide a constructive counterpart. If a disruption-neutral settlement rule exists, then every fixed-network core payoff is network-stable under that rule. Moreover, any baseline settlement rule can be converted into a disruption-neutral rule through transfers that balance within every induced settlement.

Definition 7 (Balanced-budget transfer system)**.** Fix a baseline settlement rule $\tilde{\sigma}$. A *balanced-budget transfer system* is a function r that assigns to each feasible withholding event $(S, \hat{L})$ a vector $r(S, \hat{L}) \in \mathbb{R}^{N_{\mathcal{E}}}$ satisfying

$$\sum_{n \in N_{\mathcal{E}}} r_n(S, \hat{L}) = 0.$$

The induced mitigated rule is

$$\sigma^M(\hat{L}, S) = \tilde{\sigma}(\hat{L}, S) + r(S, \hat{L}).$$

Theorem 3 (Core-preserving mitigation)**.** *Fix an economy $\mathcal{E}$. If σ is a disruption-neutral settlement rule, then*

$$NS(\mathcal{E}, \sigma) = Core(\Gamma(\mathcal{E}, L)).$$

Furthermore, for every baseline settlement rule $\tilde{\sigma}$, there exists a balanced-budget transfer system r such that the induced mitigated rule σ^M is disruption neutral and satisfies

$$NS(\mathcal{E}, \sigma^M) = Core(\Gamma(\mathcal{E}, L)).$$

Core preservation follows because every payoff in the fixed-network core gives each coalition at least its full-network worth, while disruption neutrality ensures that no rights-holding coalition can obtain more than that worth through link withholding. Hence, every fixed-network core payoff automatically satisfies both intra-network and inter-network stability. The balanced-budget part of the theorem is an implementation observation once a disruption-neutral rule exists. Moving from an induced-core allocation selected by the baseline rule to the one selected by the disruption-neutral rule requires only zero-sum transfers because both allocations are efficient in the same settlement game.

Disruption neutrality is sufficient but not necessary for preserving the entire fixed-network core. Online Appendix C provides an example in which a coalition has full-network worth zero but can guarantee a positive payoff after withholding under the punishment rule. Thus, that coalition has a positive irreducible disruption rent, and the punishment rule is not disruption neutral. Nevertheless, every full-network core payoff already gives positive payoff because of the core constraint generated by its matching opportunity. The resulting inter-network constraint, therefore, imposes a lower bound already implied by the full-network core and does not eliminate any core payoffs.

More generally, positive disruption rents need not shrink the core when they can be absorbed by preexisting slack in the relevant fixed-network core constraints. The exact preservation criterion is more permissive than disruption neutrality, but it is also coalition-specific and depends endogenously on both the geometry of the fixed-network core and the settlement rule. Theorem 3 provides a strong but transparent benchmark: eliminating disruption rents altogether guarantees full-core preservation and allows implementation via any initial settlement rule through balanced-budget transfers.

6.3. Centralization and its limits

A different way to control disruption incentives is to concentrate all cross-link rights in a single agent. This guarantees the existence of a network-stable payoff under every settlement rule, but it need not preserve the entire fixed-network core.

Proposition 3 (Stable centralization)**.** *Let $\Lambda = (G, I, P, L, \tau)$ be a network structure such that there exists an agent $a \in G \cup I \cup P$ satisfying*

$$\tau(e) = a \quad \textit{for every } e \in E.$$

Then, for every surplus vector $v \in \mathbb{R}^L$ and every settlement rule σ for the economy $\mathcal{E} = (\Lambda, v)$,

$$NS(\mathcal{E}, \sigma) \neq \emptyset.$$

The proof constructs an extremal full-network core payoff that gives the centralized access-right holder the residual surplus after all other trading agents receive their unmatched values. Every coalition capable of withholding a cross-link must contain the centralized rights holder. Since withholding cannot increase the grand coalition's maximum attainable surplus, the constructed payoff satisfies the inter-network stability constraints under every settlement rule.

Centralization and disruption neutrality operate on different margins. Centralization changes the allocation of access rights: by placing control of every cross-link in a single agent, it guarantees the existence of at least one network-stable payoff under every settlement rule. Disruption neutrality is instead a property of settlement design for a given ownership structure: it guarantees that every payoff in the full-network core remains network-stable. Generally, centralized control can support a particular extremal stable allocation without neutralizing all disruption rents or preserving the entire fixed-network core. Online Appendix D provides an example.

7. Discussion

7.1. Electricity Markets, RTOs, and Access Governance

Although the model is general, organized wholesale electricity markets provide the closest institutional analogy. Generators correspond naturally to the supply side, while load-serving entities, marketers, or other purchasers provide an interpretation of the firm side. In a meshed power system, a link should not be read literally as one transmission line joining a particular generator and purchaser. Rather, the link represents a trading opportunity whose feasibility depends on the available transmission system. The active network then summarizes the opportunities that remain feasible after outages, operating limits, schedules, and curtailments. The settlement rule represents, in reduced form, the pricing, clearing, mitigation, and payment rules that determine payoffs once that operational state is known.

The institutional history of U.S. electricity markets illustrates why physical ownership and operational control must be distinguished. The Federal Energy Regulatory Commission (FERC) mandated open access after finding that transmission-owning utilities had used control of the network to discriminate against competing suppliers, and the relevant assertion of federal jurisdiction was upheld in *New York v. FERC* (Federal Energy Regulatory Commission, 1996; Supreme Court of the United States, 2002). FERC subsequently concluded that functional unbundling left continuing opportunities for transmission discrimination and promoted independent regional transmission organizations (Federal Energy Regulatory Commission, 1999). Later experience showed that availability manipulation was not merely hypothetical. During the Western Energy Crisis, generation operators scheduled maintenance outages during peak demand and transmission paths were overscheduled to create apparent congestion and reduce available supply (Federal Energy Regulatory Commission, 2024). Related work shows that transmission-rights owners may benefit from reducing capacity made available to the market and that reported operational failures can respond to market prices (Bushnell, 1999; Fogelberg and Lazarczyk, 2019).

Independent system operators provide a useful, though imperfect, institutional counterpart to the model. ISO New England, for example, administers day-ahead and real-time markets under a FERC-approved tariff and uses a two-settlement system of charges and credits to reconcile forward positions with realized production and consumption (ISO New England Inc., Internal Market Monitor, 2025). Its market-monitoring rules expressly address physical withholding. A transmission facility may be treated as withheld when it is not operated in accordance with ISO instructions and the resulting conduct causes congestion; claimed forced and maintenance outages are subject to verification. The Internal Market Monitor investigates the reasons for apparent withholding and its market impact before sanctions are considered, while suspected tariff or manipulation violations are referred to FERC. The ISO also applies ex ante mitigation by substituting reference values for offers that satisfy specified market-power screens, with the mitigated values entering market clearing and, where applicable, settlement (ISO New England Inc., 2026).

These institutions act on distinct objects in the model. Open-access, must-offer, and outage-review requirements restrict which network changes are feasible and therefore reduce $\mathcal{L}_{\mathcal{E}}(S)$. Operational control and dispatch authority change who can effectively determine link availability. Reporting requirements and market monitoring support observability of $(S, \hat{L})$. Pricing, mitigation, and settlement rules affect σ by changing how the surplus available on an induced network is distributed. Ex post sanctions operate outside our core-valued settlement rule, but can further deter the initial withholding action. Likewise, actual ISO charges and credits do not literally implement the balanced-budget transfers in Theorem 3; the parallel is that a market institution can condition payments on the realized network and observed conduct to move the market toward a more competitive allocation.

In this interpretation, Proposition 3 is a result about unified effective authority over availability, not a prescription that an ISO acquire legal title to all transmission assets. Centralization guarantees the existence of some network-stable payoff, but it need not preserve the full fixed-network core or eliminate irreducible disruption rents. By contrast, Lemma 2 identifies the exact boundary for what core-valued settlement design can accomplish: when irreducible rents vanish, balanced-budget payment adjustments can preserve the entire fixed-network core; when there exist irreducible rents, no such settlement can reduce the coalition's induced payoff to its full-network worth. Natural-gas markets confront a related access problem through open-access transportation and capacity-release rules, and some observers have proposed a gas ISO to coordinate pipelines and electric-system operators (Federal Energy Regulatory Commission, 1992; Monitoring Analytics, LLC, 2019). These parallels show that governance of operational access and design of post-disruption payments are separate policy margins, without necessarily implying that centralization or integration is always desirable.

7.2. Scope and Future Work

Settlement institutions and externalities. The settlement rule is an institutional primitive rather than the equilibrium outcome of a specified bargaining or market-clearing protocol. This is what permits the results to apply pointwise across bargaining, pricing, and regulatory responses, while punishment maximality and irreducible rents identify conclusions robust to every admissible response. The settlement rule is also the precise connection to partition-function games. Link withholding creates a genuine externality across coalitions, but the paper does not propose a universal solution for arbitrary partition-function games. It uses a case-by-case, self-enforcing response to price each withholding opportunity and thereby obtain a characteristic-function representation. A natural extension would be to derive σ from a particular bargaining process, auction, or regulated settlement mechanism.

Dynamics, information, and richer feasibility. The analysis covers one clearing-and-settlement window, with binary and publicly observed link availability, one-to-one matching, transferable utility, and a fixed assignment of access rights. Actual infrastructure markets involve quantities, capacities, network flows, many-to-many trade, uncertain outages, repeated interaction, and endogenous investment or acquisition of access rights. These extensions may change both the existence of induced-core settlements and the set of feasible disruptions. The structural conditions in this paper should also be read as sufficient rather than exhaustive: in Online Appendix B, the dispersed-rights example shows that instability extends beyond market gates and concentrated components, while the large-market result is conditional on the specified random network-and-ownership model.

The central distinction survives these qualifications. Fixed-network stability asks whether coalitions wish to rearrange trade on the network they are given. Network stability asks whether they first wish to change that network. The settlement-rule reduction makes the latter question tractable, while disruption rents distinguish incentives that can be addressed through settlement design from those that require stronger governance of access.

Bipartite networks. The bipartite structure in our model is not the source of the network disruption externality. The underlying mechanism requires only that coalitions can alter feasibility and that each resulting active network induces a cooperative settlement problem. Once a response rule assigns a self-enforcing settlement to each induced environment, the algebraic representation in Theorem 1 extends to any finite transferable-utility setting in which induced settlement cores are nonempty and removing links cannot expand the grand coalition's opportunities. Bipartiteness nevertheless performs substantive work here: it delivers nonempty settlement cores through assignment-game duality and supplies the simple 2×2 structures used in the structural impossibility theorem. Extending the specific existence and impossibility results to nonbipartite or general trading networks therefore requires new conditions on the induced settlement games.

Appendix

Proof of Lemma 1. Fix an economy $\mathcal{E}$ and an active network $\hat{L}$. Let $T = G \cup I$ be the set of trading agents and let $\hat{E} = \hat{L} \cap E$ be the set of active cross-links.

We first define an outer matching game on T in which coalitions are constrained by the active network but not by access rights. For each $S \subseteq T$, let

$$\mathcal{M}^{out}_{\mathcal{E},\hat{L}}(S) = \{M_\mu(S) : \mu \text{ is a matching of } S \text{ and } M_\mu(S) \subseteq \hat{L}\},$$

and define

$$W_{\mathcal{E},\hat{L}}(S) = \max_{M \in \mathcal{M}^{out}_{\mathcal{E},\hat{L}}(S)} \sum_{l \in M} v_l.$$

The maximization is well defined because every trading agent in S can remain unmatched and $E^0 \subseteq \hat{L}$.

Following the linear-programming duality argument of Shapley and Shubik (1971), we first show that $(T, W_{\mathcal{E},\hat{L}})$ has a nonempty core. We adapt their argument to the assignment problem on the active bipartite graph $(G, I, \hat{E})$. Consider the linear program

$$\begin{aligned}
\max_{x \geq 0} \quad & \sum_{(g,i) \in \hat{E}} v_{(g,i)} x_{gi} + \sum_{g \in G} v_{(g,g)} x_g + \sum_{i \in I} v_{(i,i)} x_i \\
\text{s.t.} \quad & x_g + \sum_{i:(g,i) \in \hat{E}} x_{gi} = 1, && g \in G, \\
& x_i + \sum_{g:(g,i) \in \hat{E}} x_{gi} = 1, && i \in I.
\end{aligned}$$

This is the bipartite assignment polytope on the active graph, augmented by the self-link variables.[11] Hence the program has an optimal integral solution corresponding to a matching, and its value is $W_{\mathcal{E},\hat{L}}(T)$. The dual problem is

$$\begin{aligned}
\min_{u \in \mathbb{R}^T} \quad & \sum_{g \in G} u_g + \sum_{i \in I} u_i \\
\text{s.t.} \quad & u_g + u_i \geq v_{(g,i)}, && (g,i) \in \hat{E}, \\
& u_g \geq v_{(g,g)}, && g \in G, \\
& u_i \geq v_{(i,i)}, && i \in I.
\end{aligned}$$

[11] Relative to the standard assignment problem, restricting feasibility to $\hat{E}$ only deletes cross-link columns, so the constraint matrix remains totally unimodular.

Let u^* be an optimal dual solution. By strong duality,

$$\sum_{n \in T} u_n^* = W_{\mathcal{E},\hat{L}}(T).$$

Moreover, for any coalition $S \subseteq T$ and any $M \in \mathcal{M}^{out}_{\mathcal{E},\hat{L}}(S)$, each agent in S appears in exactly one link of M. Dual feasibility therefore implies

$$\sum_{l \in M} v_l \leq \sum_{n \in S} u_n^*.$$

Taking the maximum over $M \in \mathcal{M}^{out}_{\mathcal{E},\hat{L}}(S)$ gives

$$W_{\mathcal{E},\hat{L}}(S) \leq \sum_{n \in S} u_n^* \quad \text{for every } S \subseteq T.$$

Thus u^* is in the core of the outer game.

Now extend u^* to a payoff vector $\bar{u} \in \mathbb{R}^{N_\mathcal{E}}$ by setting

$$\bar{u}_n = \begin{cases} u_n^*, & n \in T, \\ 0, & n \in P. \end{cases}$$

We verify that $\bar{u} \in Core(\Gamma(\mathcal{E}, \hat{L}))$. Efficiency holds because the grand coalition contains all access-right holders, so every active cross-link is controlled by the grand coalition. Hence

$$\mathcal{M}_{\mathcal{E},\hat{L}}(N_\mathcal{E}) = \mathcal{M}^{out}_{\mathcal{E},\hat{L}}(T),$$

and therefore

$$V_{\mathcal{E},\hat{L}}(N_\mathcal{E}) = W_{\mathcal{E},\hat{L}}(T) = \sum_{n \in T} u_n^* = \sum_{n \in N_\mathcal{E}} \bar{u}_n.$$

It remains to check coalitional stability. Fix any $S \subseteq N_\mathcal{E}$ and write $S_T = S \cap T$. Any matching feasible for S in the settlement game is also feasible for S_T in the outer game, because the outer game imposes the same active-network constraint and drops the access-right constraint. Thus

$$\mathcal{M}_{\mathcal{E},\hat{L}}(S) \subseteq \mathcal{M}^{out}_{\mathcal{E},\hat{L}}(S_T),$$

and so

$$V_{\mathcal{E},\hat{L}}(S) \leq W_{\mathcal{E},\hat{L}}(S_T).$$

Since u^* is in the core of the outer game,

$$W_{\mathcal{E},\hat{L}}(S_T) \leq \sum_{n \in S_T} u_n^*.$$

By the definition of $\bar{u}$,

$$\sum_{n \in S_T} u_n^* = \sum_{n \in S} \bar{u}_n.$$

Combining the last three equations gives

$$V_{\mathcal{E},\hat{L}}(S) \leq \sum_{n \in S} \bar{u}_n.$$

Thus $\bar{u}$ satisfies every settlement-game core constraint, and $Core(\Gamma(\mathcal{E}, \hat{L})) \neq \emptyset$. $\square$

Proof of Theorem 1. Fix an economy $\mathcal{E}$ and associated settlement rule σ. We first show that:

$$U_{\mathcal{E},\sigma}(N_{\mathcal{E}}) = V_{\mathcal{E},L}(N_{\mathcal{E}}). \tag{2}$$

If $N_{\mathcal{E}} \notin \mathcal{S}^R_{\mathcal{E}}$, the equality follows directly from the definition of $U_{\mathcal{E},\sigma}$. Suppose instead that $N_{\mathcal{E}} \in \mathcal{S}^R_{\mathcal{E}}$. For any $\hat{L} \in \mathcal{L}_{\mathcal{E}}(N_{\mathcal{E}})$, by the definition of a settlement rule $\sigma(N_{\mathcal{E}}, \hat{L}) \in Core(\Gamma(\mathcal{E}, \hat{L}))$. Hence

$$\sum_{n \in N_{\mathcal{E}}} \sigma_n(N_{\mathcal{E}}, \hat{L}) = V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}}).$$

Since $\hat{L} \subseteq L$, every matching feasible for the grand coalition under $\hat{L}$ is feasible under L. Therefore

$$V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}}) \leq V_{\mathcal{E},L}(N_{\mathcal{E}}).$$

It follows that

$$B_{\mathcal{E},\sigma}(N_{\mathcal{E}}) = \max_{\hat{L} \in \mathcal{L}_{\mathcal{E}}(N_{\mathcal{E}})} \sum_{n \in N_{\mathcal{E}}} \sigma_n(N_{\mathcal{E}}, \hat{L}) \leq V_{\mathcal{E},L}(N_{\mathcal{E}}).$$

Thus

$$U_{\mathcal{E},\sigma}(N_{\mathcal{E}}) = \max\{V_{\mathcal{E},L}(N_{\mathcal{E}}), B_{\mathcal{E},\sigma}(N_{\mathcal{E}})\} = V_{\mathcal{E},L}(N_{\mathcal{E}}),$$

which proves (2).

We prove part (i) by showing both inclusions. First, let $u \in NS(\mathcal{E}, \sigma)$. By intra-network stability, $u \in Core(\Gamma(\mathcal{E}, L))$, so core efficiency gives

$$\sum_{n \in N_{\mathcal{E}}} u_n = V_{\mathcal{E},L}(N_{\mathcal{E}}).$$

By (2), this is equal to $U_{\mathcal{E},\sigma}(N_{\mathcal{E}})$, so u is efficient in $\Psi(\mathcal{E},\sigma)$.

It remains to verify the coalitional constraints of $\Psi(\mathcal{E},\sigma)$. Since $u \in Core(\Gamma(\mathcal{E},L))$,

$$\sum_{n\in S} u_n \geq V_{\mathcal{E},L}(S) \quad \text{for every } S \subseteq N_{\mathcal{E}}.$$

If $S \notin \mathcal{S}^R_{\mathcal{E}}$, then $U_{\mathcal{E},\sigma}(S) = V_{\mathcal{E},L}(S)$, so the desired inequality follows. If $S \in \mathcal{S}^R_{\mathcal{E}}$, then inter-network stability gives

$$\sum_{n\in S} u_n \geq B_{\mathcal{E},\sigma}(S).$$

Combining the last two inequalities yields

$$\sum_{n\in S} u_n \geq \max\{V_{\mathcal{E},L}(S), B_{\mathcal{E},\sigma}(S)\} = U_{\mathcal{E},\sigma}(S).$$

Thus u satisfies every core constraint of $\Psi(\mathcal{E},\sigma)$, and hence $u \in Core(\Psi(\mathcal{E},\sigma))$. Therefore

$$NS(\mathcal{E},\sigma) \subseteq Core(\Psi(\mathcal{E},\sigma)).$$

Conversely, let $u \in Core(\Psi(\mathcal{E},\sigma))$. Core efficiency in $\Psi(\mathcal{E},\sigma)$ and (2) imply

$$\sum_{n\in N_{\mathcal{E}}} u_n = U_{\mathcal{E},\sigma}(N_{\mathcal{E}}) = V_{\mathcal{E},L}(N_{\mathcal{E}}),$$

so u is efficient in the full-network settlement game. Moreover, core stability in $\Psi(\mathcal{E},\sigma)$ gives

$$\sum_{n\in S} u_n \geq U_{\mathcal{E},\sigma}(S) \quad \text{for every } S \subseteq N_{\mathcal{E}}.$$

Since $U_{\mathcal{E},\sigma}(S) \geq V_{\mathcal{E},L}(S)$ for every coalition S, it follows that

$$\sum_{n\in S} u_n \geq V_{\mathcal{E},L}(S) \quad \text{for every } S \subseteq N_{\mathcal{E}}.$$

Thus $u \in Core(\Gamma(\mathcal{E},L))$, so u satisfies intra-network stability. Finally, for every $S \in \mathcal{S}^R_{\mathcal{E}}$, we have $U_{\mathcal{E},\sigma}(S) \geq B_{\mathcal{E},\sigma}(S)$, and therefore

$$\sum_{n\in S} u_n \geq B_{\mathcal{E},\sigma}(S).$$

Hence u also satisfies inter-network stability. Thus $u \in NS(\mathcal{E},\sigma)$, and

$$Core(\Psi(\mathcal{E},\sigma)) \subseteq NS(\mathcal{E},\sigma).$$

The two inclusions prove part (i).

Part (ii) follows from part (i) and the Bondareva–Shapley theorem (Bondareva, 1963; Shapley, 1965). Since $\Psi(\mathcal{E},\sigma)$ is a finite transferable-utility characteristic-function game, its core is nonempty if and only if the game is balanced. We use the equivalent proper-coalition formulation of balancedness stated in the theorem: if a balanced collection assigns positive weight to $N_{\mathcal{E}}$, then either the weight on $N_{\mathcal{E}}$ is one, in which case the balancedness inequality is tautological, or the weight can be subtracted from both sides and the remaining proper-coalition weights normalized. Therefore $NS(\mathcal{E},\sigma) \neq \emptyset$ if and only if, for every balanced weighting scheme δ on nonempty proper coalitions,

$$\sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) U_{\mathcal{E},\sigma}(S) \leq U_{\mathcal{E},\sigma}(N_{\mathcal{E}}).$$

Part (iii) is the decomposition of the condition in part (ii). By definition,

$$U_{\mathcal{E},\sigma}(S) = V_{\mathcal{E},L}(S) + \Delta_{\mathcal{E},\sigma}(S) \quad \text{for every } S \subseteq N_{\mathcal{E}}.$$

Substituting this identity into the balancedness inequality in part (ii) gives

$$\sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) V_{\mathcal{E},L}(S) + \sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) \Delta_{\mathcal{E},\sigma}(S) \leq U_{\mathcal{E},\sigma}(N_{\mathcal{E}}).$$

Using (2) and rearranging yields

$$\sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) \Delta_{\mathcal{E},\sigma}(S) \leq V_{\mathcal{E},L}(N_{\mathcal{E}}) - \sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) V_{\mathcal{E},L}(S).$$

Thus the balancedness condition in part (ii) is equivalent to the disruption-rent decomposition in part (iii). This completes the proof. □

Proof of Proposition 1. Fix an economy $\mathcal{E}$ and associated settlement rule σ. Let $u \in NS(\mathcal{E},\sigma)$. By intra-network stability,

$$u \in Core(\Gamma(\mathcal{E}, L)).$$

Intra-network stability does not depend on the settlement rule.

It remains to verify inter-network stability under σ^P. Fix any $S \in \mathcal{S}^R_{\mathcal{E}}$ and any $\hat{L} \in \mathcal{L}_{\mathcal{E}}(S)$. By definition of the punishment rule,

$$\sum_{n \in S} \sigma^P_n(S, \hat{L}) = \min_{x \in Core(\Gamma(\mathcal{E},\hat{L}))} \sum_{n \in S} x_n.$$

Since σ is a settlement rule, $\sigma(S, \hat{L}) \in Core(\Gamma(\mathcal{E}, \hat{L}))$. Therefore,

$$\sum_{n \in S} \sigma_n^P(S, \hat{L}) \leq \sum_{n \in S} \sigma_n(S, \hat{L}).$$

Taking maxima over $\hat{L} \in \mathcal{L}_{\mathcal{E}}(S)$ gives

$$B_{\mathcal{E},\sigma^P}(S) \leq B_{\mathcal{E},\sigma}(S).$$

Since u satisfies inter-network stability under σ,

$$\sum_{n \in S} u_n \geq B_{\mathcal{E},\sigma}(S).$$

Combining the last two inequalities yields

$$\sum_{n \in S} u_n \geq B_{\mathcal{E},\sigma^P}(S).$$

Because $S \in \mathcal{S}_{\mathcal{E}}^R$ was arbitrary, u satisfies inter-network stability under σ^P. Together with intra-network stability, this implies $u \in NS(\mathcal{E}, \sigma^P)$. Since u was arbitrary,

$$NS(\mathcal{E}, \sigma) \subseteq NS(\mathcal{E}, \sigma^P).$$

□

Proof of Theorem 2. We prove the result by construction. For both components, we choose a surplus vector for which the network disruption game under the punishment rule strictly violates balancedness. The punishment test then implies that the network-stable set is empty for every settlement rule. We subsequently use the strictness of the violation to extend the conclusion to a nonempty open neighborhood of that vector.

We use the following observation repeatedly. Suppose that, in an active network $\hat{L}$, the only positive cross-links are two links incident to the same trading agent x, with values $a \geq b > 0$. Let the two links connect x to distinct trading agents y_1 and y_2, and let their access rights be held by distinct pure rights holders r_1 and r_2. Then $V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}}) = a$. For any $u \in Core(\Gamma(\mathcal{E}, \hat{L}))$, the two edge-coalition constraints imply

$$u_x + u_{y_1} + u_{r_1} \geq a \quad \text{and} \quad u_x + u_{y_2} + u_{r_2} \geq b.$$

Adding these inequalities gives

$$2u_x + u_{y_1} + u_{y_2} + u_{r_1} + u_{r_2} \geq a + b.$$

Since all self-link values in the constructions below are zero, the singleton core constraints imply $u_n \geq 0$ for every player. Core efficiency gives $\sum_{n \in N_{\mathcal{E}}} u_n = a$, and therefore

$$u_x + u_{y_1} + u_{y_2} + u_{r_1} + u_{r_2} \leq a.$$

Combining the last two inequalities yields $u_x \geq b$. Hence any coalition containing x receives aggregate payoff at least b in every core allocation of the induced settlement game.

Market gate. Suppose Λ contains a market gate. Relabel the market-gate participants as in Definition 3: the trading agents are g_1, g_2, i_1, i_2, the four rights holders are $t_{11}, t_{12}, t_{21}, t_{22}$, and $\tau(g_j, i_k) = t_{jk}$. Choose α, β, γ satisfying

$$\alpha > \beta > \gamma > 0 \quad \text{and} \quad 3\gamma > \beta.$$

Set

$$v_{(g_1,i_1)} = v_{(g_1,i_2)} = \alpha, \qquad v_{(g_2,i_1)} = \gamma, \qquad v_{(g_2,i_2)} = \beta,$$

and set $v_l = 0$ for every other link $l \in L$, including all self-links. Let $\mathcal{E} = (\Lambda, v)$ and consider the punishment rule σ^P.

Since $\beta > \gamma$, the efficient full-network matching in the component uses (g_1, i_1) and (g_2, i_2). All other links have value zero, so

$$U_{\mathcal{E},\sigma^P}(N_{\mathcal{E}}) = V_{\mathcal{E},L}(N_{\mathcal{E}}) = \alpha + \beta,$$

where the first equality follows from the grand-coalition identity in Theorem 1.

Define the four edge coalitions

$$A_{11} = \{g_1, i_1, t_{11}\}, \quad A_{12} = \{g_1, i_2, t_{12}\}, \quad A_{21} = \{g_2, i_1, t_{21}\}, \quad A_{22} = \{g_2, i_2, t_{22}\}.$$

Their full-network values give

$$U_{\mathcal{E},\sigma^P}(A_{11}) \geq \alpha, \quad U_{\mathcal{E},\sigma^P}(A_{12}) \geq \alpha, \quad U_{\mathcal{E},\sigma^P}(A_{21}) \geq \gamma, \quad U_{\mathcal{E},\sigma^P}(A_{22}) \geq \beta.$$

Now define the four isolation coalitions

$$C_g^1 = \{g_1, t_{21}, t_{22}\}, \quad C_g^2 = \{g_2, t_{11}, t_{12}\}, \quad C_i^1 = \{i_1, t_{12}, t_{22}\}, \quad C_i^2 = \{i_2, t_{11}, t_{21}\}.$$

Coalition C_g^1 can withhold (g_2, i_1) and (g_2, i_2), leaving only the two positive links incident to g_1, both of value α. By the observation above, every induced-core allocation gives g_1 at least α, and hence

$$U_{\mathcal{E},\sigma^P}(C_g^1) \geq \alpha.$$

Similarly, C_g^2 can withhold the two links incident to g_1, leaving the two positive links incident to g_2, with values β and γ. Therefore,

$$U_{\mathcal{E},\sigma^P}(C_g^2) \geq \gamma.$$

Coalition C_i^1 can withhold the two links incident to i_2, leaving values α and γ incident to i_1, so

$$U_{\mathcal{E},\sigma^P}(C_i^1) \geq \gamma.$$

Coalition C_i^2 can withhold the two links incident to i_1, leaving values α and β incident to i_2, so

$$U_{\mathcal{E},\sigma^P}(C_i^2) \geq \beta.$$

Let

$$\mathcal{C} = \{A_{11}, A_{12}, A_{21}, A_{22}, C_g^1, C_g^2, C_i^1, C_i^2\}.$$

Assign weight 1/3 to each coalition in $\mathcal{C}$. Each player in the displayed market-gate component belongs to exactly three coalitions in $\mathcal{C}$. For every player outside the component, assign weight one to its singleton coalition. The resulting weights form a balanced weighting scheme on proper coalitions of the full player set. Because all self-link values are zero, the network-disruption value of each added singleton coalition is nonnegative, so these coalitions do not weaken the lower bound below.

The preceding inequalities imply

$$\sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) U_{\mathcal{E},\sigma^P}(S) \geq \frac{1}{3}(3\alpha + 3\gamma + 2\beta) = \alpha + \gamma + \frac{2\beta}{3}.$$

Since $3\gamma > \beta$,

$$\alpha + \gamma + \frac{2\beta}{3} > \alpha + \beta = U_{\mathcal{E},\sigma^P}(N_{\mathcal{E}}).$$

Thus $\Psi(\mathcal{E}, \sigma^P)$ violates balancedness strictly.

Concentrated component. Suppose instead that Λ contains a concentrated component. Relabel the concentrated-component participants as in Definition 4: the trading agents are g_1, g_2, i_1, i_2, the rights holders are t_1, t_2, and

$$\tau(g_1, i_1) = \tau(g_2, i_2) = t_1, \qquad \tau(g_1, i_2) = \tau(g_2, i_1) = t_2.$$

Choose α, β, γ satisfying

$$\alpha > \beta > \gamma > 0 \quad \text{and} \quad 2\gamma > \beta.$$

Set

$$v_{(g_1,i_1)} = v_{(g_1,i_2)} = \alpha, \qquad v_{(g_2,i_1)} = \beta, \qquad v_{(g_2,i_2)} = \gamma,$$

and set $v_l = 0$ for every other link $l \in L$, including all self-links. Let $\mathcal{E} = (\Lambda, v)$ and consider the punishment rule σ^P.

Since $\beta > \gamma$, the efficient full-network matching in the component uses (g_1, i_2) and (g_2, i_1). Hence

$$U_{\mathcal{E},\sigma^P}(N_{\mathcal{E}}) = V_{\mathcal{E},L}(N_{\mathcal{E}}) = \alpha + \beta.$$

Consider the five coalitions

$$S^1 = \{g_1, t_1, t_2\}, \quad S^2 = \{i_1, t_1, t_2\}, \quad S^3 = \{g_2, i_2, t_1\},$$

$$S^4 = \{g_1, g_2, i_1, i_2, t_1\}, \quad S^5 = \{g_1, g_2, i_1, i_2, t_2\}.$$

Coalition S^1 can withhold (g_2, i_1) and (g_2, i_2), leaving only the two positive links incident to g_1, both of value α. By the observation above,

$$U_{\mathcal{E},\sigma^P}(S^1) \geq \alpha.$$

Coalition S^2 can withhold (g_1, i_2) and (g_2, i_2), leaving the two positive links incident to i_1, with values α and β. Hence

$$U_{\mathcal{E},\sigma^P}(S^2) \geq \beta.$$

The remaining three bounds follow from full-network rematching:

$$U_{\mathcal{E},\sigma^P}(S^3) \geq V_{\mathcal{E},L}(S^3) = \gamma,$$

$$U_{\mathcal{E},\sigma^P}(S^4) \geq V_{\mathcal{E},L}(S^4) = \alpha + \gamma,$$

and

$$U_{\mathcal{E},\sigma^P}(S^5) \geq V_{\mathcal{E},L}(S^5) = \alpha + \beta.$$

Assign weights

$$\delta(S^1) = \delta(S^2) = \delta(S^3) = \delta(S^4) = \frac{1}{4}, \qquad \delta(S^5) = \frac{1}{2}.$$

Each player in the displayed concentrated component has total weight one across these coalitions. As above, assign weight one to the singleton coalition of each player outside the component. The resulting weights form a balanced weighting scheme on proper coalitions of the full player set. The added singleton coalitions have nonnegative network-disruption values and therefore do not weaken the following lower bound.

Using the preceding inequalities,

$$\sum_{\emptyset \neq S \subsetneq N_{\mathcal{E}}} \delta(S) U_{\mathcal{E},\sigma^P}(S) \geq \frac{1}{4}\alpha + \frac{1}{4}\beta + \frac{1}{4}\gamma + \frac{1}{4}(\alpha+\gamma) + \frac{1}{2}(\alpha+\beta) = \alpha + \frac{3\beta + 2\gamma}{4}.$$

Since $2\gamma > \beta$,

$$\alpha + \frac{3\beta + 2\gamma}{4} > \alpha + \beta = U_{\mathcal{E},\sigma^P}(N_{\mathcal{E}}).$$

Thus $\Psi(\mathcal{E}, \sigma^P)$ violates balancedness strictly.

We have established nonexistence at the surplus vector constructed for each ownership pattern. We complete the proof by extending the corresponding strict balancedness violation to an open neighborhood of that vector. Fix either construction above and its associated balanced weighting scheme δ. For fixed Λ, write $\mathcal{E}_v = (\Lambda, v)$. Each settlement-game value $V_{\mathcal{E}_v,\hat{L}}(S)$ is the maximum of finitely many linear functions of v and is therefore continuous in v. For each feasible withholding event $(S, \hat{L})$, define

$$b_{S,\hat{L}}(v) = \min_{u \in Core(\Gamma(\mathcal{E}_v,\hat{L}))} \sum_{n \in S} u_n.$$

This is the value of a finite parametric linear program. Its constraint matrix and objective are fixed, while its right-hand side depends continuously on v through the settlement-game values. By Lemma 1, the feasible set is nonempty for every v. It is also compact: core efficiency fixes the sum of payoffs, while the singleton core constraints give a finite lower bound for every coordinate and therefore a finite upper bound as well. Standard parametric linear-programming results then imply that $b_{S,\hat{L}}(v)$ is continuous in v.

For fixed Λ and S, the set $\mathcal{L}_{\mathcal{E}_v}(S)$ does not depend on v and is finite. Hence

$$B_{\mathcal{E}_v,\sigma^P}(S) = \max_{\hat{L}\in\mathcal{L}_{\mathcal{E}_v}(S)} b_{S,\hat{L}}(v)$$

is continuous in v. It follows that $U_{\mathcal{E}_v,\sigma^P}(S)$ is continuous in v for every coalition S.

Denote the degree of the balancedness violation by:

$$F(v) = \sum_{\emptyset\neq S\subsetneq N_{\mathcal{E}_v}} \delta(S)U_{\mathcal{E}_v,\sigma^P}(S) - U_{\mathcal{E}_v,\sigma^P}(N_{\mathcal{E}_v}).$$

The preceding argument implies that F is continuous. In each construction, $F(v) > 0$ at the displayed surplus vector. Therefore, there exists a nonempty open neighborhood $\mathcal{O}_\Lambda$ of that vector such that $F(v) > 0$ for every $v \in \mathcal{O}_\Lambda$. For every such v, the network disruption game $\Psi(\mathcal{E}_v, \sigma^P)$ is not balanced. By Corollary 1,

$$NS(\mathcal{E}_v, \sigma) = \emptyset$$

for every settlement rule σ for $\mathcal{E}_v$. Hence Λ is structurally unstable. □

Proof of Proposition 2. Fix $\omega \geq 2$ and let $m = \lfloor\omega/2\rfloor$. We select m vertex-disjoint 2×2 candidate submarkets in the following manner: For each $r = 1, \ldots, m$, consider the submarket induced by generators $\{g_{2r-1}, g_{2r}\}$ and firms $\{i_{2r-1}, i_{2r}\}$. Let $A_r(\omega)$ be the event that the rth candidate submarket is a market gate.

For $A_r(\omega)$ to occur, all four cross-links in the candidate submarket must be present, and their access rights must be assigned to four distinct pure rights holders. The four links are present with probability p^4. Conditional on their existence, each link's rights holder is drawn independently and uniformly from the $\omega^2 + 2\omega$ potential holders, of whom ω^2 are pure rights holders. Therefore,

$$\Pr(A_r(\omega)) = p^4 \frac{\omega^2}{\omega^2+2\omega}\frac{\omega^2-1}{\omega^2+2\omega}\frac{\omega^2-2}{\omega^2+2\omega}\frac{\omega^2-3}{\omega^2+2\omega}.$$

For each $j \in \{0, 1, 2, 3\}$,

$$\lim_{\omega\to\infty} \frac{\omega^2-j}{\omega^2+2\omega} = 1,$$

so $\Pr(A_r(\omega)) \to p^4$. Since $p > 0$, there exists ω_p such that

$$\Pr(A_r(\omega)) \geq \frac{p^4}{2}$$

for every $\omega \geq \omega_p$.

The events $A_1(\omega), \dots, A_m(\omega)$ are independent because the selected candidate submarkets use disjoint sets of links, while link-existence and ownership draws are independent across links. Hence, for every $\omega \geq \omega_p$,

$$\Pr\left(\bigcap_{r=1}^{m} A_r^c(\omega)\right) = (1 - \Pr(A_r(\omega)))^m \leq \left(1 - \frac{p^4}{2}\right)^m.$$

If at least one event $A_r(\omega)$ occurs, then Λ_ω contains a market gate and is structurally unstable by Theorem 2. Therefore,

$$1 - \Pr(\Lambda_\omega \text{ is structurally unstable}) \leq \Pr\left(\bigcap_{r=1}^{m} A_r^c(\omega)\right) \leq \left(1 - \frac{p^4}{2}\right)^{\lfloor \omega/2 \rfloor}.$$

Let

$$a_p = 1 - \frac{p^4}{2} \in (0,1) \quad \text{and} \quad \kappa_p = -\frac{1}{2}\ln(a_p) > 0.$$

Since $\lfloor \omega/2 \rfloor = \omega/2 + d_\omega$, where $d_\omega \in \{0, -1/2\}$,

$$a_p^{\lfloor \omega/2 \rfloor} = a_p^{d_\omega} a_p^{\omega/2} = a_p^{d_\omega} e^{-\kappa_p \omega} \leq a_p^{-1/2} e^{-\kappa_p \omega}.$$

Combining the preceding inequalities, for every $\omega \geq \omega_p$,

$$0 \leq 1 - \Pr(\Lambda_\omega \text{ is structurally unstable}) \leq a_p^{-1/2} e^{-\kappa_p \omega}.$$

Because $a_p^{-1/2}$ is a finite constant that does not depend on ω, it follows that

$$1 - \Pr(\Lambda_\omega \text{ is structurally unstable}) = O(e^{-\kappa_p \omega}).$$

□

Proof of Lemma 2. We first show that (i) and (ii) are equivalent.

Take an arbitrary coalition $S \in \mathcal{S}_{\mathcal{E}}^R$. By definition, $\Delta_{\mathcal{E},\sigma^P}(S) = 0$ if and only if

$$U_{\mathcal{E},\sigma^P}(S) = V_{\mathcal{E},L}(S)$$

that is, they are equivalent when S cannot claim disruption rents. Because, $U_{\mathcal{E},\sigma^P}(S) = \max\{V_{\mathcal{E},L}(S), B_{\mathcal{E},\sigma^P}(S)\}$, this implies:

$$B_{\mathcal{E},\sigma^P}(S) \leq V_{\mathcal{E},L}(S).$$

Because S was arbitrary, the claim holds for every $S \in \mathcal{S}_{\mathcal{E}}^R$, which is exactly disruption neutrality of σ^P. The converse follows by reversing the argument.

We next show that (ii) and (iii) are equivalent. If σ^P is disruption neutral, then a disruption-neutral settlement rule exists, namely σ^P. Conversely, suppose there exists a disruption-neutral settlement rule σ. Fix any feasible withholding event $(S, \hat{L})$. Since $\sigma(S, \hat{L}) \in Core(\Gamma(\mathcal{E}, \hat{L}))$, the definition of the punishment rule gives

$$\sum_{n \in S} \sigma_n^P(S, \hat{L}) = \min_{x \in Core(\Gamma(\mathcal{E}, \hat{L}))} \sum_{n \in S} x_n \leq \sum_{n \in S} \sigma_n(S, \hat{L}).$$

Since σ is disruption neutral,

$$\sum_{n \in S} \sigma_n(S, \hat{L}) \leq B_{\mathcal{E},\sigma}(S) \leq V_{\mathcal{E},L}(S).$$

Therefore

$$\sum_{n \in S} \sigma_n^P(S, \hat{L}) \leq V_{\mathcal{E},L}(S)$$

for every feasible withholding event $(S, \hat{L})$, so σ^P is disruption neutral. This proves the equivalence.

□

Proof of Theorem 3. We begin by proving the core preservation claim. By definition, network stability requires intra-network stability, so

$$NS(\mathcal{E}, \sigma) \subseteq Core(\Gamma(\mathcal{E}, L)).$$

For the reverse inclusion, take any $u \in Core(\Gamma(\mathcal{E}, L))$. Then, for every coalition $S \subseteq N_{\mathcal{E}}$,

$$\sum_{n \in S} u_n \geq V_{\mathcal{E},L}(S).$$

In particular, this holds for every $S \in \mathcal{S}_{\mathcal{E}}^R$. Since σ is disruption neutral,

$$V_{\mathcal{E},L}(S) \geq B_{\mathcal{E},\sigma}(S) \quad \text{for every } S \in \mathcal{S}_{\mathcal{E}}^R.$$

Therefore,

$$\sum_{n \in S} u_n \geq V_{\mathcal{E},L}(S) \geq B_{\mathcal{E},\sigma}(S) \quad \text{for every } S \in \mathcal{S}_{\mathcal{E}}^R.$$

Thus u satisfies all inter-network stability constraints. Since u also satisfies intra-network stability by assumption, $u \in NS(\mathcal{E}, \sigma)$. Hence

$$Core(\Gamma(\mathcal{E}, L)) \subseteq NS(\mathcal{E}, \sigma).$$

Combining the two inclusions gives

$$NS(\mathcal{E}, \sigma) = Core(\Gamma(\mathcal{E}, L)).$$

Next, we prove the mitigation claim. Fix any settlement rule $\tilde{\sigma}$. For every feasible withholding event $(S, \hat{L})$ and every player $n \in N_{\mathcal{E}}$, define

$$r_n(S, \hat{L}) = \sigma_n(S, \hat{L}) - \tilde{\sigma}_n(S, \hat{L}).$$

Because $\sigma(S, \hat{L})$ and $\tilde{\sigma}(S, \hat{L})$ both belong to $Core(\Gamma(\mathcal{E}, \hat{L}))$, both are efficient in the same induced settlement game:

$$\sum_{n \in N_{\mathcal{E}}} \sigma_n(S, \hat{L}) = \sum_{n \in N_{\mathcal{E}}} \tilde{\sigma}_n(S, \hat{L}) = V_{\mathcal{E}, \hat{L}}(N_{\mathcal{E}}).$$

Hence

$$\sum_{n \in N_{\mathcal{E}}} r_n(S, \hat{L}) = 0,$$

so r is balanced budget. The mitigated rule satisfies

$$\sigma^M(S, \hat{L}) = \tilde{\sigma}(S, \hat{L}) + r(S, \hat{L}) = \sigma(S, \hat{L})$$

for every feasible withholding event. Therefore σ^M is disruption neutral, which by core preservation implies,

$$NS(\mathcal{E}, \sigma^M) = Core(\Gamma(\mathcal{E}, L)).$$

□

Proof of Proposition 3. Let a be the agent that controls every cross-link. Under the maintained no-slack convention for pure rights holders, no pure rights holder exists other than possibly a. Write $T = G \cup I$ for the set of trading agents, and define

$$T_a = \begin{cases} T \setminus \{a\}, & \text{if } a \in T, \\ T, & \text{if } a \in P. \end{cases}$$

Consider the payoff vector u defined by

$$u_n = v_{(n,n)} \quad \text{for every } n \in T_a,$$

and

$$u_a = V_{\mathcal{E},L}(N_{\mathcal{E}}) - \sum_{n \in T_a} v_{(n,n)}.$$

We first show that $u \in Core(\Gamma(\mathcal{E}, L))$. Efficiency holds by construction. Let $S \subseteq N_{\mathcal{E}}$. If $a \notin S$, then S controls no cross-link, so it can use only the self-links of its trading agents. Hence

$$V_{\mathcal{E},L}(S) = \sum_{n \in S \cap T} v_{(n,n)} = \sum_{n \in S} u_n.$$

If $a \in S$, take any feasible matching for S under the full network and add the self-links of all trading agents in $T \setminus S$. The resulting matching is feasible for the grand coalition under L. Therefore

$$V_{\mathcal{E},L}(S) + \sum_{n \in T \setminus S} v_{(n,n)} \leq V_{\mathcal{E},L}(N_{\mathcal{E}}).$$

By the definition of u,

$$\sum_{n \in S} u_n = V_{\mathcal{E},L}(N_{\mathcal{E}}) - \sum_{n \in T \setminus S} v_{(n,n)} \geq V_{\mathcal{E},L}(S).$$

Thus $u \in Core(\Gamma(\mathcal{E}, L))$, so u satisfies intra-network stability.

It remains to verify inter-network stability. Let $S \in \mathcal{S}^R_{\mathcal{E}}$. Since all cross-links are controlled by a, any coalition that can withhold a cross-link must contain a. Fix any $\hat{L} \in \mathcal{L}_{\mathcal{E}}(S)$ and let $y = \sigma(S, \hat{L})$. Since $y \in Core(\Gamma(\mathcal{E}, \hat{L}))$,

$$\sum_{n \in N_{\mathcal{E}}} y_n = V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}})$$

and

$$\sum_{n \in N_{\mathcal{E}} \setminus S} y_n \geq V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}} \setminus S).$$

Because $a \in S$, the coalition $N_{\mathcal{E}} \setminus S$ controls no cross-link. Therefore

$$V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}} \setminus S) = \sum_{n \in (N_{\mathcal{E}} \setminus S) \cap T} v_{(n,n)}.$$

It follows that

$$\sum_{n\in S} y_n = V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}}) - \sum_{n\in N_{\mathcal{E}}\setminus S} y_n \leq V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}}) - \sum_{n\in (N_{\mathcal{E}}\setminus S)\cap T} v_{(n,n)}.$$

Since $\hat{L} \subseteq L$,

$$V_{\mathcal{E},\hat{L}}(N_{\mathcal{E}}) \leq V_{\mathcal{E},L}(N_{\mathcal{E}}).$$

Therefore

$$\sum_{n\in S} y_n \leq V_{\mathcal{E},L}(N_{\mathcal{E}}) - \sum_{n\in T\setminus S} v_{(n,n)} = \sum_{n\in S} u_n.$$

Since this holds for every $\hat{L} \in \mathcal{L}_{\mathcal{E}}(S)$, it also holds after maximizing over $\hat{L}$:

$$B_{\mathcal{E},\sigma}(S) \leq \sum_{n\in S} u_n.$$

Thus u satisfies inter-network stability. Together with intra-network stability, this implies $u \in NS(\mathcal{E}, \sigma)$. □

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