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Networks and Markets: The Dynamic Impacts of Information, Matching and Transaction Costs on Trade

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Networks and Markets
The dynamic impacts of information, matching and transaction costs on trade *

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Abstract

The purpose of this paper is to explore strategic incentives to use trade networks rather than markets and shed light on the dynamic relation between the two distinct trading systems: a formal system of markets and a decentralised system of networks. We investigate the issues in the infinitely repeated multi-player prisoner's dilemma game with random matching. The existing literature emphasises the importance of information transmission in sustaining long-run cooperation in repeated personal transactions under perfect observability. By contrast, we show that a folk theorem may hold if we change the way traders are matched, without introducing any information sharing. We also examine different stages of the evolution of trading system. The study states conditions under which agents prefer to trade on networks rather than in markets.

Key Words: Repeated trade; Moral hazard; Matching; Transaction costs; Networks; Institutions

JEL Classification: F10, C73, D02

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1 Introduction

Despite the existence of advanced markets in the modern economy, personal links (networks) still have a quantitatively important impact on global transactions. For example, ethnic Chinese networks have a quantitatively important impact on global trade (Rauch and Trindade [10]). Why do rational agents use networks rather than markets to trade globally? What is the outcome of network trade? Is economic efficiency achieved by network trade?

This paper examines strategic incentives to use trade networks and sheds light on the dynamic relation between two distinct global trading systems: a formal system of markets and a nonmarket (decentralised) system of networks. The purpose of this paper is to investigate how unconventional factors such as personal links, various information structures, transaction costs and matching friction, which have been neglected in traditional trade theory, affect trading behaviour of agents, efficiency of trade and the dynamic relation of trading systems.

Trade economists recognise that even in the modern era of advanced information and transportation technologies, there is generally huge ambiguity in global trade compared to local goods exchange (cf. Harrigan and Venables [5]). As pointed out by Greif [4], because of complexity and uncertainty in long-distance transactions, the outcome of international trade depends on many realisations that could not be directly observed by traders involved. For example, variable factors, such as accidents during long-distance shipping, lack of information about markets and suppliers and about local institutions and regulations, the condition in which goods would arrive, difficulty in monitoring contracts and the impossibility of face-to-face frequent contact, contribute to ambiguity in global trade.

Global trade is characterised by great uncertainty and it is especially difficult for global traders to observe trading partners' behaviour and such imperfect observability induces incentive problems. Trading truthfully to each other (or obedience of unbinding agreements) yields the best outcome to both traders involved. However, because traders cannot observe their respective partners' behaviour perfectly, each agent has strategic incentives to deceive one's partners in order to increase own payoff without being noticed that he has cheated on the partners.[3] We model such situation where traders exchange commodities with uncertainty over the actions of trading partners as a two-sided moral hazard game, the prisoner's dilemma, with imperfect monitoring. We are interested in examining when the moral hazard is replaced by mutually beneficial (cooperative) trades.

Jackson and Watts [6] investigate network trade from a perspective of network formation games. In the first stage, agents simultaneously form costly links; in the following stage, the linked agents trade to a Walrasian equilibrium. The study implicitly assumes the existence of a perfect market despite the fact that only the limited number of players who strategically chose to belong to the network can trade. Instead, we regard that a decentralised system of networks and a formal system of markets are distinct trading institutions and substitutes.

The trading game is modelled as the infinitely repeated multi-player prisoner's dilemma with random matching. We investigate the roles of variable information and monitoring structures in global trade: public-information and personal-information games; perfect and imperfect monitoring. Section 2 examines a primitive trading world where there exists only a decentralised system of networks and markets have not yet evolved. Under the public-information structure where in every period each player observes the actions played in every match, the section studies two different trading situations whether partner's behaviour is observable or not.

[3] We take the standard view in economics that individuals only care about their own utility and enforceable contracts are costly.

Section 3 departs from the primitive trading world and examines the modern situation where as a result of the evolution of markets, there are two distinct trading systems: a decentralised system of networks and a formal system of markets. Agents who use a network interact with a partner, but cannot perfectly monitor their partner's performance or rely on an external enforcement mechanism; agents who use a market incur transaction costs, but performance is perfectly monitored and agreements can be legally enforced. Network interaction generates problems of two-sided moral hazard, because agents cannot observe whether poor performance was due to their partner shirking or to bad luck, such as accidents during long-distance shipping. We assume that punishments can be carried out personally only within a match.

Section 4 studies a personal-information game with imperfect monitoring where agents only observe the outcome of matches imperfectly in which they personally involved in a decentralised trading system of networks. The section aims to explore the relation between matching and efficiency. Kandori [7] explores frictionless random matching personal-information games and has greatly focused on the role of information sharing in sustaining long-run cooperation in a trading community with a large population.

In a society with a large number of agents, if agents who terminate a personal trading relationship can wipe away any record of their past behaviour and find a new partner with an extreme matching rule (i.e. finding a partner immediately after a partnership termination), no information survives the termination of a match. In such a situation, there are no punishments that can sustain effort and all players behave myopically since their continuation payoffs are independent of whether they have defected or not.

Therefore Kandori [7] departs from the situation and introduces information transmission among the traders. When information about deviators is shared among the society members, they can coordinate their punishments against deviators and deter cheating behaviour. Kandori [7], therefore, argues that when there is a large number of players in a trading community, what matters for long-run economic efficiency (a folk theorem) is information transmission among the members.

By contrast, Section 4 explores the role of matching in sustaining long-run cooperation and efficiency in an infinitely repeated personal-history matching game without introducing information sharing. The literature assumes that players are randomly rematched in each period to play the stage-game. We depart from the conventional assumption that players are randomly rematched in each period to play the stage-game and the history of each player can be shared among the other members through information transmission.

We, instead, examine the situation where it is frictional to establish a trading partnership and players have no information about each player's history before the partnership. The section constructs an equilibrium for a decentralised trading system of networks and demonstrates that a folk theorem may hold if we change the way in which agents are matched in a network, without introducing any information sharing. In particular, we show the upper bound of the likelihood of establishing a personal trading relation that supports an efficient equilibrium. The result generalises Kandori [7].

Section 5 investigates the situation where each agent chooses one of the two distinct trading systems: a network or a market. We examine favourable factors for cooperation in a network and show conditions under which agents prefer to trade on networks rather than in markets. Section 6 discusses this paper in comparison with the existing literature in the field of study. Section 7 concludes.

2 Public Information Games

The trade game is modelled as the infinitely repeated multi-player prisoner's dilemma with random matching. We consider public-information games where in every period each player perfectly (perfect monitoring) or imperfectly (imperfect monitoring) observes the actions played in every match.

2.1 Perfect Monitoring

Players engage in international trade where each trade relation is personal: two traders meet and exchange commodities. The interval $I = [0, 1]$ represents the set of players. Each agent lives an infinite number of periods and has the common time discount factor $\delta \in (0, 1)$. Players are randomly rematched in each period to play the stage-game.

The game is the prisoner's dilemma in which each player takes actions "effort" (e) or "shirk" (s) simultaneously. At the end of each period, every player observes the actions played in every match. Player i's stage-game payoff is defined by $g_i(a)$, where a is the action profile played in own match in the period. The stage-game payoffs are described in Table 1:

Table 1: The stage-game payoffs

	e	s
e	ψ, ψ	$\beta - \alpha, \alpha$
s	$\alpha, \beta - \alpha$	0, 0

where the parameters α, β and ψ are finite numbers, and $\beta - \alpha < 0 < \psi < \alpha$ and $2\psi > \beta$ (cooperation is the best outcome). Each player's total payoff is the expected sum of his stage payoffs discounted by δ.

The strategy profile σ is the grim trigger profile: it calls for the players to exert efforts in the first period and continue to exert efforts until a player shirks, after which players shirk against the deviator forever. Attention is restricted to strongly symmetric equilibria where two players choose the same actions in every period after any history. Simultaneous deviations are ignored. Then play can be in one of two possible states: a cooperative phase where both players exert efforts and a punishment phase where both players play the static Nash equilibrium in each period.

The equilibrium concept we use is subgame perfection since histories are public and each history leads to a subgame. Players have no incentive to deviate from a punishment phase since the punishment strategy of shirking is the only static Nash equilibrium in a stage-game of prisoner's dilemma and therefore self-enforcing.

Let $v_i^{'}$ be the continuation payoff after playing e, and $\underline{v_i}$ be the continuation payoff after playing s. Hence,

$$v_i^{'} = (1-\delta)\psi + \delta v_i^{'} . \tag{1}$$

Under the strategy σ, once a player plays s, his play enters a punishment phase. Therefore $\underline{v_i} = 0$. The incentive constraint that no one gains by cheating

$$v_i^{'} \geq (1-\delta)\alpha + \delta \underline{v_i}$$

is rewritten as

$$\psi \geq (1-\delta)\alpha. \tag{2}$$

The optimal trigger equilibria will lead to $v_i^{'}$ given by equation (1) subject to the incentive constraint (2) that no player gains by deviating from a cooperative phase. Hence, there exists an equilibrium in the public-history game in which action profile (e, e) is played by every pair of matched players in period $t = 0, 1, 2, ..$ if and only if for any α and ψ players are sufficiently patient (large δ), or for any δ the gain from deviation α is sufficiently small relative to the gain from cooperation ψ. Hence, we have the following result.

Proposition 1. *In the public information games with perfect monitoring, v_i' is sustained by a subgame perfect equilibrium if and only if*
(1) for any α and ψ, players are sufficiently patient, or
(2) for any δ, the instant stage-game gain from cheating is sufficiently small.

Increasing patience increases the weight on future payoffs for the fixed stage-game payoffs while lowering the instant gain from cheating $(\alpha - \psi)$ reduces the temptation to defect from an equilibrium prescription of high efforts for a fixed discount factor. The intuition for the result is that any deviation from σ triggers the most severe punishments from the repeated game. Although partnerships are alterable and a deviator never meets with matched partners again in the future, severe punishments are still possible since information is public.

2.2 Imperfect Monitoring

We next examine the situation where two traders meet and exchange commodities with uncertain qualities. Players are rematched each period. Each player takes unobservable actions "effort" (e) or "shirk" (s) simultaneously. Player i's effort level $a_i = \{e, s\}$ affects the quality of the good he provides to player j ($i \neq j$ and $i, j \in I$).

At the end of each period, a signal realises for a transaction between matched traders. The signal set is $Y = \{\overline{y}, \underline{y}\}$. The first element is denoted by a good signal and the second by a bad signal. The probability distribution of the signal is given by $\pi(\overline{y} \mid a) = p$ if $a = ee$ and $\pi(\overline{y} \mid a) = q$ if $a = se$ or es, where $0 < q < p < 1$.[4] The distribution is conditional on the strategy profile a and captures the situation where a signal is more likely to be good if both traders exert efforts and bad if one shirks. Player i's expected stage-game

[4]The probability when both shirk is irrelevant in this analysis and thus omitted.

payoff is defined by $g_i(a) = \sum_{y \in Y} r_i(a_i, y)\pi(y \mid a)$, where $r_i(a_i, y)$ is player i's stage-game payoff after the realisation (a_i, y).

Traders follow the trigger strategy σ: play e in the first period, and play e against players whose past signals are always good and play s in each period forever regardless of the public signals against players with a bad signal ever observed in the past. In every period, each player observes the signals realised in every match. The expected stage-game payoffs are given in Table 1.

A sequence of the realised public signals is called *public history*. The public information available in period t is the t-period history of public signals, which is denoted by $h^t = (y^1, y^2, ..., y^{t-1}) \in Y^{t-1}$. The set of public history is $H = \cup_{t=0}^{\infty} Y^t$, where $Y^0 = \emptyset$. The equilibrium concept we use is perfect public equilibrium (PPE): a profile $\sigma_i = \sigma_1, ..., \sigma_I$ of repeated-game strategies is a perfect public equilibrium if (1) each σ_i is a public strategy where players condition their actions on public information (signals), and (2) for each date t and history h^t, the strategies yield a Nash equilibrium from that date on. The remaining settings are the same as before.

Let $v_i^{'}$ be the continuation payoff after the realisation of a good signal, and $v_i^{''}$ be the continuation payoff after the realisation of a bad signal. Hence,

$$v_i^{'} = (1-\delta)\psi + \delta \left[p v_i^{'} + (1-p) v_i^{''} \right]$$

becomes

$$v_i^{'} = \frac{1-\delta}{1-\delta p}\psi. \tag{3}$$

Under the strategy σ, play against players with the history of a bad signal enters a punishment phase. Therefore $v_i^{''} = 0$. The incentive constraint that no one gains by cheating is

$$v_i^{'} \geq (1-\delta)\alpha + \delta \left[q v_i^{'} + (1-q) v_i^{''} \right].$$

From (3), the constraint is written as

$$\frac{(1-\delta q)\psi}{(1-\delta p)\alpha} \geq 1. \tag{4}$$

As $p > q$ and $\alpha > \psi$, inequality (4) implies that effort is supported in every match when signals are sufficiently informative and players are sufficiently patient for any α and ψ. When signals are informative, for any stage-game payoffs, patient players have incentives to exert efforts to make good signals realise more likely so that they receive higher expected future payoffs.

Effort is also supported in every match if and only if the gain from cheating α is sufficiently small for any δ, p and q. If the gain from cheating is sufficiently small, cheating is not attractive so that players exert efforts no matter how patient they are and how informative signals are. Hence, we have the following result.

Proposition 2. *In the public information game with imperfect monitoring, σ is a PPE if and only if*
(1) for any α and ψ, signals are informative enough and players are sufficiently patient, or
(2) for any δ, p and q, the gain from cheating is sufficiently small.

3 Evolution of Markets

In this section, we consider the situation where markets have evolved and there are two distinct trading systems: a decentralised system of networks and a formal system of markets. In a market, there are an infinite number of traders preexist and two players are randomly rematched to trade in each period. Agents who use a market incur the transaction cost $\tau \in (0, \psi)$, but performance is perfectly monitored and agreements on exerting efforts can be legally enforced. Market trade yields the stage-game payoff of $\psi - \tau$.

The game in a network is the same as in the previous section except the following. The strategy profile calls for the agents to play e in the first period and continue to play e until a bad signal is observed after which the players enter a market for T periods to reset own past history and begin another match in the network. There is no penalty attached to entering a market. If a trader decides to remain in the network after a bad signal or if a player comes back to the network without staying in a market for T periods, his play enters a punishment phase where his partners shirk in each period regardless of signals.

Let $v_i^{'}$ be the continuation payoff after the realisation of a good signal, and $v_i^{''}$ be the continuation payoff after the realisation of a bad signal. Hence,

$$v_i^{'} = (1-\delta)\psi + \delta \left[p v_i^{'} + (1-p) v_i^{''} \right] \tag{5}$$

and

$$v_i^{''} = (1-\delta^T)(\psi - \tau) + \delta^T v_i^{'} ,$$

which yields

$$v_i^{'} = \frac{\psi(1-p\delta) - \delta(1-p)\left\{(\psi-\tau)\delta^T + \tau\right\}}{1 - p\delta - \delta^{T+1}(1-p)} \tag{6}$$

and

$$v_i^{''} = \frac{(1-p\delta)\left\{\psi - \tau(1-\delta^T)\right\} - \delta^{T+1}\psi(1-p)}{1 - p\delta - \delta^{T+1}(1-p)} . \tag{7}$$

By using equation (5), the incentive constraint that no one gains by shirking

$$v_i^{'} \geq (1-\delta)\alpha + \delta \left[q v_i^{'} + (1-q) v_i^{''} \right] \tag{8}$$

is rewritten as

$$\frac{\delta}{1-\delta}(p-q)(v_i^{'}-v_i^{''}) \geq \alpha - \psi\,. \tag{9}$$

The constraint (9) implies that cooperation is sustained either when players are patient enough or when the gain from cheating is sufficiently small, provided signals are informative enough. It tells that players cooperate if the future gain from cooperation (the left-hand side of (9)) is greater than the instant gain from cheating (the right-hand side of (9)).

By using equations (6) and (7), the constraint (9) is rewritten as

$$\frac{\delta\tau(p-q)(1-\delta^T)}{1-p\delta-\delta^{T+1}(1-p)} \geq \alpha - \psi\,. \tag{10}$$

As $T \to 0$, the left-hand side of condition (10) approaches 0 so that the incentive constraint does not hold for any parameter values. For sufficiently small T, the incentive constraint never holds and cooperation is not sustained by any equilibrium. The intuition for this is that if players do not need to stay in a market long enough to reset own 'bad' past record, they have incentives to cheat since increasing the probability of a bad outcome by cheating does not harm their continuation payoffs enough to prevent them from shirking.

Proposition 3. *Suppose players are far-sighted and signals are informative enough, or the gain from cheating is sufficiently small. There exists the minimum number T^* such that long-run cooperation is supported in the network trading game.*

Effort is supported in a match as long as the punishment period T is sufficiently large relative to the incentives to shirk, given that players are far-sighted and signals are informative enough, or the gain from cheating is sufficiently small.

4 Matching and Efficiency in a Trade Network

We next explore the personal-information game where agents only observe the outcome of matches in which they personally involved. In games with a large population of players it would be reasonable to assume that players have limited information about other players' actions or signals. In this section, we construct an equilibrium for a decentralised trading system of networks in order to investigate the outcome of network trade and efficiency. We demonstrate when economic efficiency (a folk theorem) holds for network trade.

Players engage in international trade where each trading partnership is personal: two traders meet and exchange commodities. The interval $N = [0, 1]$ represents the set of players. Each agent lives an infinite number of periods and has a common time discount factor $\delta \in (0, 1)$. Players are randomly rematched in the first period to play the stage-game. The stage-game is the prisoner's dilemma in which each player takes unobservable actions "effort" (e) or "shirk" (s) simultaneously. The model captures the repeated exchange of commodities with uncertain qualities. Player i's effort level $a_i = \{e, s\}$ affects the quality of the good he provides to player j ($i \neq j$ and $i, j \in N$).

At the end of each period, a signal realises for a transaction between matched traders. The signal set is $Y = \{\overline{y}, \underline{y}\}$. The first element denotes a good signal and the second a bad signal. The probability distribution of the signal is given by $\pi(\overline{y} \mid a) = p$ if $a = ee$ and $\pi(\overline{y} \mid a) = q$ if $a = se$ or es, where $0 < q < p < 1$.[5] The distribution is conditional on the strategy profile a and captures the situation where a signal is more likely to be good if both traders exert efforts and bad if one shirks. Player i's expected stage-game

[5]The probability when both shirk is irrelevant in this analysis and thus omitted.

payoff is defined by $g_i(a) = \sum_{y \in Y} r_i(a_i, y)\pi(y \mid a)$, where $r_i(a_i, y)$ is player i's stage-game payoff after the realisation (a_i, y). The expected stage-game payoffs are given in Table 1.

Network traders follow the trigger strategy σ: play e in the first period, and play e as long as each period's signal is good and once a bad signal happens play s in each period forever regardless of the signals. Network traders only observe the outcome of matches in which they personally involved. They have a choice to enter a market and there is no penalty attached to entering a market. In a market, there are an infinite number of traders preexist and two players are randomly rematched to trade in each period. Agents who use a market incur the transaction cost $\tau \in (0, \psi)$, but performance is perfectly monitored and agreements on exerting efforts can be legally enforced. Market trade yields the stage-game payoff of $\psi - \tau$.

When a bad signal happens in period t, a player decides whether to go to a market or to remain in the network from the period $t + 1$. If either player in the relationship chooses to engage in market trade, the relation terminates in period t. After a termination of the partnership, the players trade in a market from $t + 1$ until they find another partner with probability θ in a market to come back to a network.

A network relation continues only when both partners remain in the network. If a player remains in the network while the partner enters a market, the player receives no gain from trade in each period unless he enters a market. Punishments can be carried out only within a match. If two network traders decide to continue the relationship after a bad signal, play enters a punishment phase where both traders play the static Nash equilibrium in each period regardless of signals.

Then network trading game is determined recursively. The strategy σ calls for the network players to play as follows:

1. $t = 0$ is a cooperative phase;

2. if t is a cooperative phase and the signal in period t is good, then the relation continues followed by a cooperative phase in $t+1$;
3. if t is a cooperative phase and the signal in period t is bad, then the relation terminates in t. From $t+1$, both players enter the market with probability θ to find a new trading partner in the network to start playing from 1 above.

In the following part, we investigate conditions for a PPE in which players always exert effort. Let $v_i^{'}$ be the continuation payoff after the realisation of a good signal and $v_i^{''}$ be the continuation payoff after the realisation of a bad signal and not finding a new partner. Hence,

$$v_i^{'} = (1-\delta)\psi + \delta\left[pv_i^{'} + (1-p)\left\{\theta v_i^{'} + (1-\theta)v_i^{''}\right\}\right] \tag{11}$$

and

$$v_i^{''} = (1-\delta)(\psi-\tau) + \delta\left\{\theta v_i^{'} + (1-\theta)v_i^{''}\right\} ,$$

which yields

$$v_i^{'} = \frac{\psi - \delta(1-\theta)\left\{(1-p)\tau + p\psi\right\}}{1-p\delta(1-\theta)} \tag{12}$$

and

$$v_i^{''} = \frac{(\psi-\tau)(1-p\delta) + \delta\theta\left\{p(\psi-\tau)+\tau\right\}}{1-p\delta(1-\theta)} . \tag{13}$$

After observing a good signal $\overline{y}$, agents in a cooperative phase continue the relationship if and only if the continuation payoff from terminating it is at most the same as the continuation payoff from continuing it

$$\theta v_i^{'} + (1-\theta)v_i^{''} \leq v_i^{'} \Leftrightarrow v_i^{''} \leq v_i^{'} . \tag{14}$$

By using equations (12) and (13), the condition (14) is rewritten as

$$\delta \leq 1 . \tag{15}$$

This always holds.

Agents in a cooperative phase do not attempt to trade with the same partner after observing a bad signal $\underline{y}$ if and only if the continuation payoff from continuously playing with the same partner is at most the same as the continuation payoff from terminating the relation

$$0 \leq \theta v_i^{'} + (1-\theta) v_i^{''}. \tag{16}$$

The condition (16) is rewritten as

$$-v_i^{''} \leq \theta (v_i^{'} - v_i^{''}) \, .$$

Since $v_i^{'} - v_i^{''} \geq 0$ from (14) and $v_i^{''} > 0$ from (13) for any parameter values, the condition (16) always holds. The incentive constraint that no player gains by deviating in a cooperative phase is

$$v_i^{'} \geq (1-\delta)\,\alpha + \delta \left[q v_i^{'} + (1-q) \left\{ \theta v_i^{'} + (1-\theta) v_i^{''} \right\} \right]. \tag{17}$$

From (12) and (13), this condition is rewritten as (18). Then we have the following claim.

Proposition 4. *The strategy σ is a PPE in which players always exert efforts if and only if*

$$\theta \leq 1 - \frac{\alpha - \psi}{\delta \left\{ p(\alpha - \psi) + \tau (p-q) \right\}}. \tag{18}$$

When matching is sufficiently frictional, self-enforcing cooperation is the outcome for the network trading game. As $\theta \to 1$, it is optimal for network players to choose myopic behaviour by shirking even if the reservation (market) payoff is not very favourable due to the high transactions cost τ. This is because increasing probability of bad signal by shirking does not harm one's future payoff as θ approaches 1. The threat of breaking the personal relationship never deters shirking when θ is sufficiently large so that the unique equilibrium in a network is mutual shirking.

This result generalises Kandori [7] (Proposition 3) in which $\theta = 1$ is implicitly assumed. The intuition for the Kandori's result and Proposition 4 is that, as Milgrom et al. [8] point out, with a large population of players and the extreme matching rule ($\theta = 1$) where no player can affect his opponents' future play in any way, for any parameter values of stage-game payoffs, patience and signal accuracy, cheating is the only Nash equilibrium outcome. We have departed from the extreme matching rule and demonstrated that matching friction is a factor that would bring mutually beneficial transactions over time in the personal-information game.

Let $\overline{\theta}$ be the upper bound of θ with which long-run cooperation is supported under σ. Then

$$\overline{\theta} = 1 - \frac{1}{p\delta + \frac{\delta\tau(p-q)}{\alpha-\psi}} .$$

Hence, probability $\overline{\theta}$ is a well defined probability when $p\delta + \frac{\delta\tau(p-q)}{\alpha-\psi} \geq 1$ holds. Suppose δ is sufficiently large. The value of $\overline{\theta}$ is a well-defined probability when signals are informative enough for any α, ψ and τ, or when the gain from a one-shot deviation α is sufficiently small for any p, q, ψ and τ. Hence, we have the following claim.

Proposition 5. *Suppose players are sufficiently patient, and signals are informative enough or α is sufficiently small. There exists a $\overline{\theta} \in [0, 1)$ such that* *for all $\theta \in [0, \overline{\theta}]$, there is an equilibrium in the personal-information game with perfect monitoring that attains the efficient point (ψ, ψ).*

Proof. The most efficient PPE maximises the sum of the two players' payoffs. Let v_i^* be the highest payoff in any pure-strategy symmetric equilibrium. Both players must exert effort in the first period to support the equilibrium payoff v_i^*. Then the efficient average equilibrium payoff v_i^* satisfies (11) and (17). Since by definition $v_1^* + v_2^* \geq v_1^{'} + v_2^{'}$, from (11) and (17), the following formula is obtained:

$$v_1^* + v_2^* \leq 2\psi - \frac{2(\alpha - \psi)(1-p)}{p-q}. \tag{19}$$

The efficient point (ψ, ψ) is attainable when $p = 1$.

□

The result indicates that a folk theorem holds only when monitoring is perfect in the personal-information game. The efficiency loss, captured by the second term of the right-hand side in (19), is independent of δ and θ. This is the inefficiency studied in Radner, Myerson and Maskin [9]. In the prisoner's dilemma game with imperfect public monitoring with two signals, efficiency loss is inevitable no matter how patient agents are and how less likely a player finds a new partner. This is because there is a positive probability to observe a bad signal on the equilibrium path of long-run cooperation.

5 Choice Between Networks and Markets

The section investigates conditions under which agents prefer to trade on networks rather than in markets. Agents choose a trading system in period 0 in order to maximise own lifetime payoff. The average payoff to player i who chooses a market is $v_i^m = \psi - \tau$.

By rearranging (18), we obtain a trader's best response of exerting efforts if and only if

$$\psi \geq \frac{\alpha - \delta(1-\theta)\left\{p\alpha + \tau(p-q)\right\}}{1 - p\delta(1-\theta)} \equiv \psi^* > 0.$$

Let ψ^* be the *optimal gain from network trade*, which is the lowest gain from network trade for which it is a trader's best response to exert efforts in the absence of external enforcement. The trader's strategy calls for exerting efforts if one gains ψ^* and shirking if one gains less than ψ^*.

Proposition 6. *The favourable factors for network trade are sufficiently small α and θ, sufficiently large δ and τ, and informative signals.*

Proof. The relationships between ψ^* and the variables α, τ, θ, δ, p and q are
$\partial\psi^*/\partial\tau = -\delta(p-q)(1-\theta)/G < 0$,
$\partial\psi^*/\partial\alpha = 1$,
$\partial\psi^*/\partial\delta = -\tau(p-q)(1-\theta)/G^2 < 0$,
$\partial\psi^*/\partial\theta = \delta\tau(p-q)/G^2 > 0$,
$\partial\psi^*/\partial p = -\delta\tau(1-\theta)\left\{1 - q\delta(1-\theta)\right\}/G < 0$ and
$\partial\psi^*/\partial q = \delta\tau(1-\theta)/G^2 > 0$,
where $G = 1 - p\delta(1-\theta) > 0$.

□

The optimal gain from network trade $\psi^* = \Psi(\tau, \alpha, \delta, \theta, p, q)$ is monotonically increasing in α, θ and q, and monotonically decreasing in δ, τ and p. Network traders are more likely to cooperate when (a) they are more far-sighted, (b) the stage-game payoff from a deviation $\alpha - \psi$ is sufficiently small, (c) the transaction cost τ is sufficiently large, (d) signals are informative enough (large $p - q$) and (e) finding a personal trading partner is sufficiently frictional (small θ).

When (a) to (e) hold, playing s is less attractive for players who value future over present since cheating currently does not yield a very large gain now while significantly increases the chance of entering into a market where they gain far less than now in each period until one can find another partner with low probability. Under the conditions of (a) to (e), agents do not choose myopic behaviour of shirking and cooperative trading behaviour is self-enforced in networks.

Suppose cooperation is sustained in networks, players choose networks than markets if and only if the average gain from market trade is at most the same as the gain from network trade, i.e. $v' \geq \psi - \tau$, which is rewritten as $\delta(1-\theta) \leq 1$. This always hold for any parameter values. Hence, when networks are a cooperative trading system, players strictly prefer to trade on a network rather than in a market in order to receive the higher average payoff from network trade.

By contrast, if cooperation is not supported in networks (i.e. mutual shirking is the equilibrium), players choose a market rather than a network because the average payoff from market trade is greater than the one from network trade, $\psi - \tau \geq 0$. The following result states when traders prefer networks to markets.

Proposition 7. *Agents prefer to trade on networks than in markets when they are patient, matching is frictional, the gain from a deviation is sufficiently small, the transaction cost is sufficiently large and the signals are informative enough.*

6 Related Literature and Discussion

By looking into 11th-century Mediterranean trade, Greif [4] shows that opportunistic behaviour is deterred in long-run agency employment relations governed by a coalition because cheating is punished by the whole coalition over time. In the infinitely repeated principal-agent game with a large population, Greif assumes that agents are randomly paired with a trading partner in each period and only observe the outcome of matches in which they personally involved.

As they can share information of cheaters, collective punishment is available in the trading group. Because of such communication among traders, probability of finding a new trading partner in the future, which is conditional on one's private history, is zero if one ever cheats in the past. In the study, the results depend on the assumption that exchanging the information about cheaters among the coalition members. However, the process of such information transmission is not explicitly modelled in the study. Therefore, the game itself is the public information game with perfect monitoring.

We then depart from the primitive trading world and examine the modern situation where as a result of the evolution of markets, there are two distinct trading systems: a decentralised system of networks and a formal system of markets. Two randomly matched network traders play cooperatively until a bad outcome is observed after which they enter a market for a fixed period to reset own past history and come back to the network again.

Bowles and Gintis [1] study the relation between market and nonmarket institutions. The study explores a static situation where there is a coordination failure described as the prisoner's dilemma, though the one-shot game does not consider dynamic interaction between the distinct trading systems. In order to avoid trading with preexisting untrustworthy members, agents communicate to obtain information about the type of respective partners and mix their actions according to signal accuracy. They study how differences in social traits among trading members influence the signal accuracy and communication.

Kandori [7] examines a nonmarket trading game in the infinitely repeated multi-player prisoner's dilemma with random matching. The paper shows that when traders only observe the outcome of personally involved matches and do not share the information with the others, a folk theorem fails as the population of traders becomes large.

He then introduces a decentralised device which always processes information honestly but does not have any enforcement power of its own. In a personal-information game with contagion strategies, once a deviation occurs cheating contagiously spreads through the trading community. The information device facilitates community enforcement of efficient trade since the community members can collectively identify deviators and lower the continuation payoffs of them. Information sharing functions to deter the myopic incentive of deviation. Kandori argues that when there are a large number of players, what matters for economic efficiency in a trade community is not changing partners but information transmission among them.

The result is based on the implicit assumption that establishing personal relations is not frictional at all (i.e. $\theta = 1$ in this model). In repeated games with a large population, when establishing economic relations is frictionless with no information flow among players about deviators, the situation becomes similar to playing the prisoner's dilemma in each period over time with a different opponent. As Proposition 4 indicates, with a large population of players and the extreme matching rule ($\theta = 1$) where no player can affect his opponents' play in any way, cheating is the only Nash equilibrium outcome.[6]

[6]By focusing on this feature, several studies have investigated the possibility that large population models may be used to reduce the multiplicity of equilibria in repeated games (Rosenthal [11], Green [3], Sabourian [12]).

In such a situation, information sharing is crucial for efficiency.

In games with a large population of players, it would be reasonable to assume that players have limited information about other players' actions. This study demonstrates that we could sustain long-run mutually beneficial trade by focusing on matching rather than information sharing in repeated decentralised transactions. Fujiwara-Greve and Okuno-Fujiwara [2] investigate a similar situation where a large number of agents are randomly matched to play the prisoner's dilemma repeatedly until either partner wants to break up the relation. The study analyses a possibility of long-run cooperation with no information flow apart from the behaviour of current partner. There are different types of strategies in the population and it is beneficial to match with the same type rather than with a different type. Players cooperate to avoid a break-up of the current partnership which may lead to a possible bad match. In the evolutionary model of endogenous long-run partnerships, they show that the endogenous duration of partnerships gives rise to an evolutionary stability structure.

Folk theorems in Greif [4] and Kandori [7] depend on the assumption that agents observe own partners' actions perfectly. In this study, a folk theorem holds only when monitoring is perfect. In the infinitely repeated prisoner's dilemma with two public signals, the perfect public equilibria payoff set is bounded away from the efficient frontier, no matter how patient agents are (Radner, Myerson and Maskin [9]). When monitoring is imperfect, efficiency loss is inevitable since the lower continuation payoff is followed after the realisation of bad signals which occur with positive probability on the equilibrium path. In this study, the efficiency loss, captured by the second term of the right-hand side in the formula (19), is independent of the degree of the matching friction θ.

Although a folk theorem is restricted to the situation where monitoring is perfect as in the existing literature, the paper newly shows that long-run cooperative trade may be supported in the personal-information game, without introducing information transmission among a large number of traders.

7 Conclusion

There is generally huge ambiguity in global trade compared to local goods exchange. When traders cannot observe their respective partners' behaviour perfectly, they have strategic incentives to deceive one's partners in order to increase own payoff without being punished for cheating. This paper examines the situation where agents strategically choose their trading behaviour in response to a certain trading environment and demonstrates a possibility of mutually beneficial trade over time in the absence of any external enforcement mechanisms.

The existing literature has greatly focused on the role of information transmission among traders in achieving efficiency of trade. This paper contributes to demonstrate that independent of the monitoring structure matching friction is another factor that brings self-enforcing mutually beneficial transactions over time in the personal-information game.

We show that a folk theorem may hold if matching is frictional, without introducing any information sharing though efficiency of trade is achieved only when every trader perfectly observes actions in every match or one's partners' actions. The paper also investigates conditions under which agents prefer to trade on networks rather than in markets. Matching friction, the likelihood of finding a partner in a trade network, affects agents' preferences over the trading institutions through influencing traders' incentives to cooperate in the absence of external enforcement mechanism.

This study is different from the social network formation approach. The approach investigates that networks (links) form strategically on the basis of cost-benefit analysis of agents while there is no cost to form a trading link in this study. The paper does not consider the network architecture or distance among traders so that there is no effect of the architecture on trading behaviour of agents.

We also look into different stages of the evolution of trading systems. We firstly examine primitive trading world where there exists only a decentralised system and markets have not yet evolved. We then depart from the primitive setting and examine the modern situation where as a result of an evolution of markets, there are two distinct trading systems: a decentralised system of networks and a formal system of markets. The study attempts to provide a rationale of coexistence of markets and nonmarket institutions in the modern economy by exploring the dynamic relation between the trading institutions.

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