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On the Prevalence of Online Trade among Strangers: A Game-Theoretic Explanation

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Motivated by the prevalence of online trade among strangers through consumer-to-consumer transactions, we examine by random matching the theoretical possibility of a social norm of trust and reciprocity emerging among strangers in the infinitely repeated buyer-sender game. Players are completely anonymous and interact only at randomly determined times. Based on the study by Kandori (1992), we show that the social norm of trust and the reciprocation of trust can be sustained in a population of self-interested, anonymous strangers when trust and reciprocity are attached to the community as a whole. Sufficient conditions that support trust and reciprocity as a sequential equilibrium are provided.

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I. Introduction

Trust is a key element in sustaining trade and other economic activities. Therefore, one of the most important issues in the field of Economics is to find ways to sustain such a cooperative norm when players have a short-term incentive to deviate from it. Economists have long recognized "reputation" as an effective means of enforcing "cooperation" when an institution exists to track and disseminate information on players' past behavior or within a small group, in which people are intimately familiar with one another's history. However, these personal enforcement mechanisms are only effective if quick and substantial retaliations are

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available. In repeated game literature, folk theorem (Fudenberg and Maskin, 1986) provides a formal model of personal enforcement, showing that any mutually beneficial outcome can be sustained as a subgame perfect equilibrium if the same set of players plays the same stage game ad infinitum (Kandori, 1992).

With the development of the Internet, however, a high degree of trust and reciprocity seems to emerge among essentially anonymous agents. Due to the fact that it is easy to create new identities online and agents do not encounter each other again, they do have little recourse to direct or immediate punishment. Thus, trust among Internet users is difficult to establish. Nevertheless, there is an extensive shuttling of new and second-hand goods among distant strangers through online customer-to-customer (C2C) transactions,[1] especially in the cottage industry and in small, home-based retail shops. In online trading, buyers pay considerable amounts of money with great risk due to the fact that they forward their payments even before they are able to inspect and receive the product. Sellers, on the other hand, are not met face to face, and little or nothing is known about them, their characteristics, or even their location. Given the anonymous and infrequent nature of economic transactions in online markets, many important questions arise. How do such markets work efficiently? What motivates online sellers to deliver the purchased goods at the qualities promised, knowing that they are unlikely to meet the same buyer again? What motivates buyers to trust unknown sellers when they could not actually distinguish the trustworthy from the untrustworthy ones? This paper answers these questions and illustrates how a system deters moral hazard and adverse selection.

There is little published theoretic literature on how effective electronic transactions work. Kandori (1992) examines a similar environment, in which each player is anonymous and plays a prisoner's dilemma game with any other player at randomly determined times. Even when each agent knows nothing more than his/her personal experience, Kandori shows that a community can still sustain cooperation via a "contagious strategy," in which players who defected or have previously experienced defection ultimately choose noncooperation. In the equilibrium, a deviator can be indirectly punished if the deviation triggers a contagious reaction that destroys the social norm of cooperation. If the consequences of the eventual destruction of the norm are sufficiently severe and credible, then the threat of contagious reactions might sustain the social norm of cooperation.

In this paper, we theoretically extend Kandori's (1992) idea to a binary buyer-sender game. Different from the prisoner's dilemma, the buyer-sender game well

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[1] This phenomenon can be also observed in the early stage of C2C auction sites, such as eBay or Yahoo! Auctions when the feedback or reputation system is absent or insufficiently run.

represents a one-sided incentive problem,[2] that is, knowing that the partner will cooperate, only the sender has an incentive to deviate from the cooperative outcome. Therefore, the game captures the feature of some real-life examples, such as transactions between buyers and sellers on the Internet or loan repayment in credit market, both of which have sequential-move game structures and only the second mover has an incentive problem. We examine the process of sustaining the social norm of trust and reciprocity in a community, in which a finite population of agents is randomly paired with one another every period. Players are completely anonymous; they can neither recognize nor communicate the identity of any of their past opponents. Moreover, they do not observe the outcomes of games they are not involved in or any aggregate information about the entire community.

We first develop the concept of the contagious strategy following Kandori (1992), after which we provide the sufficient conditions that support the social norm of trust and reciprocity as a sequential equilibrium. Our main results imply that the existence of contagious equilibrium critically depends on the outside option for the buyer. With a high outside option, the buyer will not go back to purchase after experiencing non-reciprocative senders, thus posing a credible threat to senders, keeping them from behaving dishonestly. In addition, the sender's extra payoff from defection needs to be larger when the discount factor is larger. That way, the sender has no incentive to slow down the contagious procedure by trustworthiness if he defected in a previous incident. Finally, the discount factor must lie in an intermediate range in order to control the senders' incentive.

This paper contributes to the field from three aspects. The first contribution is the examination of the results of the contagious equilibrium and whether or not it extends to other classes of games aside from the prisoner's dilemma. We cannot ignore the sociological difference between the prisoner's dilemma and the buyer-sender games. The buyer-sender game represents social exchange or risk taking while the prisoner's dilemma illustrates social conflict. Furthermore, as noted by Ellison (1994), the results of previous papers rely on the game structure of the prisoner's dilemma, which is characterized by i) a dominant strategy and ii) a simultaneous move. It is not obvious whether or not the similar equilibrium can extend to a game without these two features. Indeed, we find that the incentive constraints off the equilibrium path are more restricted in the buyer-sender game for both buyers and senders. This means that it is more difficult to have players always choose non-cooperative actions after experiencing defection. In Kandori's result, it is sufficient to control players' incentive if both the discounter factor and the cost of choosing cooperation when the other player chooses defection are

[2] Kandori (1992) has a formal definition of a "one-sided incentive problem" (Definition 4 on page 73). The concept requires that only one of two parties has an incentive to deviate from the cooperative outcome, and there is a Nash equilibrium, such that the payoff from the equilibrium is less than the payoff from the cooperative outcome for the party who has the incentive problem.

substantial enough. In our result, if the discounter factor is too big, the seller will have a large incentive to slow down the contagious procedure. Therefore, in equilibrium, the discounter factor must lie in the middle range.

The second contribution of the paper is the rationalization of the findings on the significant level of trust and reciprocity in many experimental studies. Berg et al. (1995) first find that the level of trust and reciprocity is significant even under the double-blind and one-shot control, and throws an open question as to how trust and reciprocity can be included in the rational choice paradigm. After their seminal work, much of the experimental papers on the trust game[3] tried to solve this issue. Some researchers working on trust-game experiments have attempted to specify subjects' preferences and explain the finding of trust and reciprocity as concerns for fairness, altruism, inequality aversion, and so on. Our model, however, provides an alternative explanation for trust and reciprocity found in those experiments. The model's design involves anonymous identity, repeated play, random matching, and observation of the outcome after each period. It is common practice in experiments to ask participants to play a game repeatedly to allow learning as well as to employ random matching after each period in order to prevent reputation effect via personal enforcement. In this kind of environment, we are able to establish that trust and reciprocity can arise simply among rational players who act for their own self-interests. However, our results call for caution in experimental design that intends to specify other related preferences.

Finally, as mentioned above, this paper helps us understand the emergence and prevalence of electronic commerce. With the development of the Internet, e-Commerce has expanded largely and has become an important component of the economy. Due to the fact that buyers and sellers are essentially anonymous on the Internet and that it is usually difficult to establish a long-term relationship between these entities, a model with random matching and anonymous identity is appropriate in describing the e-market. Our model provides one possible explanation for the prevalence of online transactions, that is, the fear of a contagious wave of defection may prevent dishonest behavior. Our result shows that the outside option needs to be large enough to make a credible threat for trustees. On the one hand, this suggests that it is important to have an alternative market place, e.g., the traditional retailers, to keep the e-market sellers alert. On the other hand, it requires the outside option to be more valuable when the market size in e-Commerce becomes larger, which means the e-market may lose its potential advantages compared with the traditional market. Therefore, the fear of contagion is more likely to facilitate e-Commerce at its early stage, when the market size is small and other institutions are underdeveloped. When the e-market becomes larger, the fear

[3] The trust game, the investment game, and the buyer-sender game have common game structures (Berg et al., 1995).

of contagion may not be enough. Other mechanisms, such as the electronic feedback system, are necessary to keep the e-market advantageous.

The paper is organized as follows. The following section discusses the related literature. Section 3 describes the model and provides the equilibrium conditions. Section 4 concludes the paper. Parts of the proofs are found in the Appendix.

II. Related Literature

This paper is mainly related to the literature on community enforcement, particularly on the contagious equilibrium. Thus, our research draws upon several prior theoretical and experimental studies.

With anonymous random matching, Kandori (1992) shows that cooperation may be possible if all players adhere to the contagious strategy, in which individuals who have not experienced defection choose "cooperation," and individuals who have either experienced defection by their opponent or have defected themselves in the past choose "defection." Specifically, he shows that for an infinite horizon and for any fixed population size, we can define payoffs for the prisoner' dilemma game that sustain cooperation in a sequential equilibrium. However, the author shows that community enforcement supports cooperation in the one-sided incentive problem but *only* under local information processing when each agent carries a label, such as reputation, membership, or license. In contrast to Kandori's (1992) result, the current paper shows that the social norm of trust and reciprocity in the one-sided incentive environment can arise as a sequential equilibrium without any information other than his/her personal experience.

Ellison (1994) extends Kandori's work and introduces a public randomization device, which adjusts the severity of the punishment. Compared to Kandori's (1992) results, the equilibrium by Ellison (1994) does not require excessive patience on the part of the players and applies to more general payoff structures. Furthermore, given public randomizations, the equilibrium strategy supports nearly efficient outcomes even when players make mistakes with a small probability.

Deb (2009) establishes a general folk theorem for anonymous random-matching games without adding any verifiable information about previous games. The paper states that for any two-player game between two communities, it is possible to sustain all feasible individually-rational payoffs in a sequential equilibrium if players are allowed to announce their names before each stage and if they are sufficiently patient. Such outcome is a strong possibility result. However, players still need to send a *message* (a name) before playing each stage of the game, even if the *message* is unverifiable, which differentiates this setting from ours.

There are several experimental studies that have tested the contagious equilibrium in the laboratory. Duffy and Ochs (2008) test Kandori's (1992) results using groups of subjects who play an indefinitely repeated two-person prisoner's dilemma under different matching protocols and amounts of information transmission. Their results show that, under fixed pairings, a social norm of cooperation develops as subjects gain experience; whereas under random matching, experience tends to drive groups toward a far more competitive norm, even when some information is provided about the prior choices of opponents. They conclude that random matching prevents the development of a cooperative norm in the laboratory.

Camera and Casari (2008) address the same issue of cooperation under random matching. However, they focus on the role of private or public monitoring of the choices of anonymous (or non-anonymous) players and find that such monitoring can lead to a significant increase in the frequency of cooperation relative to the case with no monitoring. More importantly, their result on the absence of monitoring is the first finding, which demonstrates the significant level of cooperation in favor of the contagious equilibrium.

In contrast to all these papers, the current study examines the indefinitely repeated "buyer-sender" game instead of the prisoner's dilemma game. Unlike the prisoner' dilemma game, the buyer-sender or "trust" or "investment" game (Berg et al., 1995) that we study in this paper has 1) sequential moves and 2) no dominant strategies. In particular, the first mover has an incentive to choose "trust" (rather than no trust) if he believes the second mover will reciprocate, while the second mover has an incentive to cheat (not reciprocate) if the first mover trusts him, but is otherwise indifferent to cheating or reciprocating. This game is more closely related to many real-world *one-sided incentive problems*. Furthermore, we note that most real-world reputation systems are designed to monitor the behavior of "second movers." For these reason, we think it is promising to study the buyer-sender game under anonymous random matching.

There are several experimental papers on repeated trust games that relate to this study. For instance, Bolton et al. (2004) compare the results from three treatments: a *stranger market*, where individual buyers and sellers meet no more than once and the buyer has no information about the seller's transaction history; a *feedback market*, which has the same matching rule as the stranger market and provides the seller's histories of shipping decisions to the buyer; finally, a *partners market*, in which the same buyer-seller pairs interact repeatedly in every period. A trust game with binary choices is played repeatedly for 30 periods in each session. Not surprisingly, transaction efficiency, trust, and trustworthiness (reciprocity) are all smallest in the stranger market, greater in the feedback market, and greatest in the partners market.

Charness et al. (2009) examine the effect of the different kinds of information about trustees. Subjects take turns playing both roles as first mover (investor) or second mover (trustee) in a finitely repeated version of the trust game. First movers receive information either on the history of return behavior by their matched trustee or on the history of investment (trust) decisions made by their matched trustee when that trustee plays the investor (first mover) role. They find that both types of histories can significantly increase trust, relative to the absence of such information.

Although Bolton et al. (2004) and Charness et al. (2009) investigate a finitely repeated game, none of their studies have been able to rationalize trust and trustworthiness as an equilibrium phenomenon among anonymous, randomly matched players who have no information about the history of play of their partners as is the case in our study. Thus, they do not address the issue of whether or not the mechanism that supports trust and reciprocity is possible through community-wide enforcement (i.e., fear of a contagious wave of distrust and confiscation).

The current paper also relates to literature exploring the historic development of economic institutions in fostering trade among strangers, such as the analysis on medieval trade by Greif (1989, 1993) and Milgrom et al. (1990). These papers model a large number of traders who are randomly paired with one another in each period. Each pair is presumed to play a game similar to the buyer-sender game, in which one party has an incentive to cheat the other by supplying goods of inferior quality or reneging on promises to make future payments. In this literature, institutions are seen as channels to avoid the inefficiency of noncooperative equilibria. Greif (1989) and Milgrom et al. (1990) argue that the exchange of information on the identity of cheaters or the development of a mechanism, which strengthens the power of enforcement, can help sustain cooperation. Our model, on the other hand, assumes complete anonymity among traders.

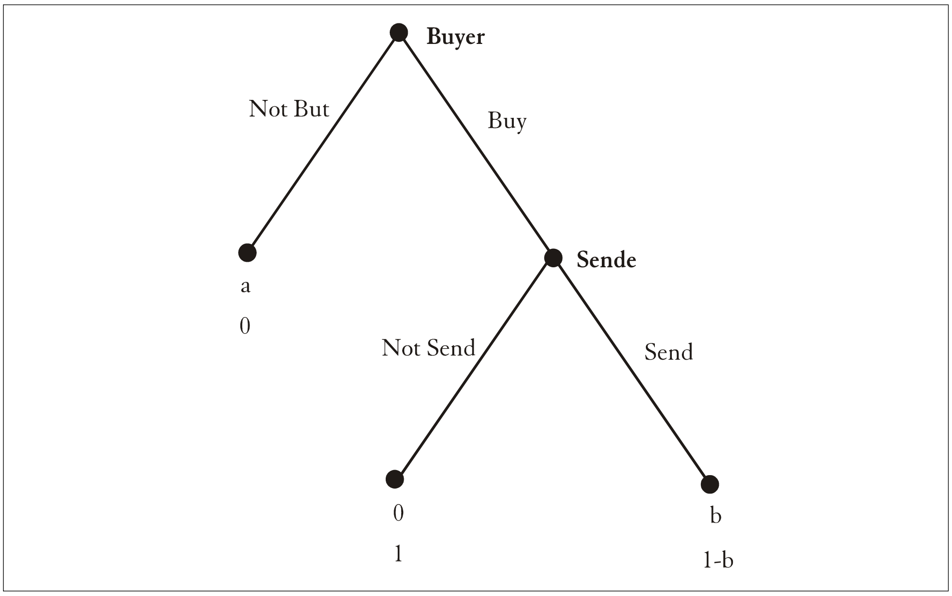
III. The Model

In this section, we first describe the structure of the repeated-matching game, define the concept of "contagious strategy" based on Kandori (1992) in the infinitely repeated buyer-sender game with random matching, and then present the conditions for the equilibrium to exist.

The set of players $N=\{1,2,3,\ldots,2n\}$ is partitioned into two sets of equal sizes: the set of buyers $N_B=\{1,2,3,\ldots,n\}$ and the set of senders $N_S=\{n+1,n+2,\ldots,2n\}$. In each period, a buyer is matched with a sender according to the uniform random matching rule. Let $\mu(i,t)$ be buyer i 's match at time t ; $\Pr\{\mu(i,t)=j\}=1/n$ for all $i\in N_B$ and $j\in N_S$ and for all t. In every period, each buyer-sender pair plays a binary buyer-sender game as a stage game described below. This procedure is repeated infinitely and each player's total payoff is the expected sum of his stage payoffs discounted by $\delta\in(0,1)$.

The binary buyer-sender game considers a trading situation, in which the buyer needs to pay first and the seller ships the good after receiving the payment. At the beginning of the game, the buyer is endowed with a unit of money and decides whether or not to buy at the sender's online shop. If the buyer decides not to buy, the game ends and she[4] gains $a<1$ from the outside option (e.g., offline shopping) and the sender gets nothing. If the buyer chooses to buy, the utility grows to 1, which is the total gain from the successful trade. The sender then decides whether or not to send the ordered good to the buyer. If the sender chooses to send, the payoff is b for the buyer and $1-b$ for the sender. If the sender decides not to send and defect, then the buyer gets nothing and the sender keeps 1 for himself. We assume that $0<a<b<1$, i.e., it is efficient for the buyer to buy, the buyer prefers the cooperative outcome (Buy, Send) to her outside option, and the sender has an incentive not to send once the buyer makes a decision to buy and pay for the item. The buyer-sender game is standardized in the sense that the total amount of utility for the two traders from successful trade is 1. The buyer-sender game and its payoff structure are described in Figure 1.

[Figure 1] The Buyer-Sender Game



This buyer-sender game is a typical example of the one-sided incentive problem. Different from the prisoner's dilemma game, the buyer-sender game is not a dominant strategy for the buyer to choose defection (i.e., not to buy). Instead, the buyer prefers successful online trade to her outside option while the sender—as a

[4] In this section, we denote the buyer as "she" and the sender as "he" for clarity.

second mover—has an incentive to deviate from the buyer's desire.

In the entire paper, we assumed that each player only observes the history of action profiles in the stage games which he/she has experienced. When paired with another player, players have no idea about the identity or previous experience of their match as well as that of any other players. Therefore, players cannot base their actions on their personal experiences with the current match, neither can their choice be based on any information on the plays between their match and other players in the community or any aggregate information about the entire community.

If the binary buyer-sender game is played once, the unique subgame perfect equilibrium requires the buyer not to buy and for the sender not to send. Although the efficient outcome cannot be achieved in the one-shot game, we illustrate below how it can be achieved in the "contagious equilibrium" when the binary buyer-sender game is infinitely repeated, even if the partners are randomly rematched after each period and a player can observe no information other than his/her own experience. We define "Not Buy" as the defection of a buyer, and "Not Send" as the defection of a sender. D-type buyers or senders are defined as those whose history includes defection by themselves or their partners; otherwise, the players are considered as c-type.

Definition *The "contagious strategy" is defined as follows: a buyer buys if she is c-type and does not buy if she is d-type. A sender sends if he is c-type and does not send if he is d-type.*

The idea of the contagious strategy is that trust and the reciprocation of trust are applied to the community as a whole, not to each individual player, since the players are anonymous. Therefore, a single defection by a member means the end of the whole community trust, and a player who experiences dishonest behavior starts defecting all of his or her opponents (Kandori, 1992). The concept of contagious strategy is especially relevant in the population of anonymous Internet users. Thanks to the anonymity and random interaction in the game, all the members tend to worry about is easy contagion of defective actions at the bottom. Now, we show that the profile of contagious strategy constitutes a sequential equilibrium and trust, from which reciprocity emerges as an equilibrium outcome for any fixed number of population.

To explore this, we introduced more notations. Let X_t be the total number of d-type buyers and Y_t be the total number of d-type senders at the beginning of period t. Let Z_t denote the state of period t. In particular, Z_t is a one-to-one and onto function from (X_t, Y_t) to the set of natural numbers $\{1,2,3,\ldots, n(n+2)\}$: $Z_t = (n+1)X_t + T_t$ for $X_t + Y_t > 0$. Let Λ be an $n(n+2)\times n(n+2)$ transition matrix with elements $\lambda_{ij} = \Pr\{Z_{t+1} = j \mid Z_t = i$, and *all players follow the contagious strategy*$\}$. Let Π be an $n(n+2)\times n(n+2)$ transition matrix with elements $\pi_{ij} = \Pr\{Z_{t+1} = j \mid Z_t = i$, *one d-type sender deviates from the contagious strategy, and all other players follow the contagious strategy*$\}$. We define ρ as an $n(n+2)\times 1$ column vector with the i th element equal to the conditional probability for the sender to meet a c-type buyer when the state is i in period t.[5] Finally, let e_i be a $1\times n(n+2)$ row vector with the i th element equal to 1 and all other elements equal to 0.

An example: Matrices Λ and Π when $n=2$.

Function Z_t assigns a different natural number to all possible combinations of (X_t, Y_t) except $X_t = Y_t = 0$.

X_t	0	0	1	1	1	2	2	2
Y_t	1	2	0	1	2	0	1	2
Z_t	1	2	3	4	5	6	7	8

Matrix Λ presents the transition probability when all players follow the contagious strategy.

	(0,1)	(0,2)	(1,0)	(1,1)	(1,2)	(2,0)	(2,1)	(2,2)
(0,1)	0	0	0	1	0	0	0	0
(0,2)	0	0	0	0	0	0	0	1
(1,0)	0	0	0	1	0	0	0	0
(1,1)	0	0	0	½	0	0	0	½
(1,2)	0	0	0	0	0	0	0	1
(2,0)	0	0	0	0	0	0	0	1
(2,1)	0	0	0	0	0	0	0	1
(2,2)	0	0	0	0	0	0	0	1

For example, $\lambda_{44} = \lambda_{48} = 1/2$ given that there is one d-type buyer and one d-type sender at the beginning of the current period and all players follow a contagious strategy. With probability at ½, these two d-type players meet each other in the current period and the state of the community does not change in the next period; with the same probability ½, these two d-type players meet the remaining innocent players; the players then become 2 d-type buyers and 2 d-type senders in the next period.

Matrix Π presents the transition probability when one d-type sender deviates from Not Send to Send and all other players follow the contagious strategy.

[5] The formulas for λ_{ij}, π_{ij}, and ρ can be found in the Appendix.

	(0,1)	(0,2)	(1,0)	(1,1)	(1,2)	(2,0)	(2,1)	(2,2)
(0,1)	1	0	0	0	0	0	0	0
(0,2)	0	0	0	0	1	0	0	0
(1,0)	0	0	0	1	0	0	0	0
(1,1)	0	0	0	½	½	0	0	0
(1,2)	0	0	0	0	½	0	0	½
(2,0)	0	0	0	0	0	0	0	1
(2,1)	0	0	0	0	0	0	0	1
(2,2)	0	0	0	0	0	0	0	1

Suppose again that there is one d-type buyer and one d-type sender at the beginning of the current period. The state in the next period does not change if they meet with each other (with probability ½). If they meet the remaining two innocent players (with probability ½), then there emerges two d-type senders and one d-type buyer since the d-type sender in the current period did not defect the innocent buyer he met. Therefore, $\pi_{44} = \pi_{45} = 1/2$ in Matrix Π . ■

In order to show a d-type sender's incentive to follow the contagious strategy, before stating the main results, we defined functions $f(\delta)$ and $g(\delta)$ as follows:[6]

$$f(\delta) \equiv \delta e_1 (\Pi - \Lambda)(I - \delta\Lambda)^{-1} \rho = \delta \sum_{t=0}^{\infty} \delta^t e_1 (\Pi - \Lambda)\Lambda^t \rho ,$$

$$g(\delta) \equiv \delta e_{n+2} (\Pi - \Lambda)(I - \delta\Lambda)^{-1} \rho = \delta \sum_{t=0}^{\infty} \delta^t e_{n+2} (\Pi - \Lambda)\Lambda^t \rho .$$

Functions $f(\delta)$ and $g(\delta)$ represent the benefits for a d-type sender to deviate one shot from the contagious strategy (i.e., Not Send forever) to choose Send in the current period (and Not Send forever afterwards), given that the current states are 1 (there is no d-type buyer and one d-type sender) and $n+2$ (there is one d-type buyer and one d-type sender), respectively. Conceptually, $f(\delta)$ represents the discounted sum of expected future payoffs (i.e., the gain) to a sender from *not* initiating a contagious wave of defection when all the other players in the community are c-types. Meanwhile, $g(\delta)$ represents the gain to a d-type sender from deviating from defection (i.e., resuming to play Send) given that there is just one d-type buyer and one d-type sender (himself) in the current period. Thus, $f(\delta)$ and $g(\delta)$ are the discounted, expected payoffs to a sender from avoiding the triggering or slowing down of the contagious strategy in the current period in

[6] Rigorous construction of the functions appears in the proof of Proposition 1.

different states of the world (i.e., when there are different numbers of d-type buyers and d-type senders in the community). Functions $f(\delta)$ and $g(\delta)$ are non-negative. This is because by deviating from the contagious strategy, a d-type sender delays the procedure for the contagion to spread over to the community and increases his own probability to meet a c-type buyer in the future.

Lemma 1 (i) $f(\delta)$ and $g(\delta)$ are continuous and increasing over $\delta \in (0,1)$;
(ii) $\lim_{\delta \to 0} f(\delta) = \lim_{\delta \to 0} g(\delta) = 0$ and $\lim_{\delta \to 1} g(\delta) < \lim_{\delta \to 1} f(\delta) = 1$;
(iii) $f(\delta) > g(\delta)$, $\forall \delta \in (0,1)$.

Lemma 1 mainly states that the benefit for a d-type sender to slow down the contagious procedure is larger when the state $Z_t = 1$ (i.e., there is no d-type buyer and one d-type sender) than the benefit when the state $Z_t = n+2$ (i.e., there is one d-type buyer and one d-type sender). Intuitively, when the d-type sender under consideration is the only d-type player, his delaying of the spreading of the contagion deters contagion completely in the community. In comparison, if there are already other d-type players, the contagion spreads anyway even if this d-type sender tries to slow down the procedure.

Below are the sufficient conditions that support the social norm of trust and reciprocity as a sequential equilibrium for any fixed number of population.

Proposition 1 *The contagious strategy constitutes a sequential equilibrium if*

$$a \geq \frac{n-1}{n} b, \tag{1}$$

and

$$g(\delta) \leq b \leq f(\delta). \tag{2}$$

Proposition 1 provides the sufficient conditions, under which one-shot deviations from the contagious strategy are not profitable after any history for both buyers and senders. Due to the one-sided incentive problem, in which the buyer prefers the cooperative outcome (Buy, Send) to her outside option, it is easy to verify that the buyer has no incentive to deviate from the equilibrium path. Condition (1) controls the buyer's incentive off the equilibrium path. This means that for a d-type buyer, she has no incentive to go back to choose Buy, even if she believes there is only one d-type sender in the community. This is the strongest condition since it is sufficient if the buyer believes there is more than one d-type senders.

Condition (2) controls the sender's incentive to deviate from the contagious strategy in both the on-the-equilibrium and off-the-equilibrium paths. As mentioned previously, functions $f(\delta)$ and $g(\delta)$ are the sender's gain from slowing down the procedure of contagion given that the states of the community are $Z_t = 1$ and $Z_t = n+2$. By definition, $f(\delta)$ can also be regarded as the gain for the sender from deterring the start of a defection, since at $Z_t = 1$, the sender is the only d-type player in the community. When the sender is on the equilibrium path, $f(\delta) \geq b$ says that the gain from deterring the start of a defection is greater than the gain from choosing Not Send (i.e., b). Therefore, the sender has no incentive to deviate from cooperation. When the sender is off the equilibrium path, $g(\delta) \leq b$ says that the benefit from slowing down the contagious procedure is less than the loss from choosing Send (which is also b); thus, the sender has no incentive to go back to the cooperative behavior once there are other d-type players in the community.

The proposition above is used as proof in Proposition 2, which states that we can always find values for a *and* b in the buyer-sender game that satisfy the sufficient conditions of Proposition 1.

Proposition 2 *Consider the random matching model described above where* $2n \geq 4$ *players play the buyer-sender game. For any* δ *and* n*, there exist* a *and* b*, such that (i)* $0 < a < b < 1$ *and (ii) the contagious strategy constitutes a sequential equilibrium in which (Buy, Send) is the outcome of every period along the equilibrium path under uniform, random matching.*

Proof of Proposition 1 and Proposition 2

As in Kandori (1992), we only have to check that one-shot deviations from the strategy are unprofitable after checking the history of both buyers and senders.

First, a one-shot deviation from the equilibrium path is unprofitable for a sender, if:

$$\frac{1-b}{1-\delta} \geq \sum_{t=0}^{\infty} \delta^t e_1 \Lambda^t \rho .$$

The left-hand side is the expected payoff from Send to the buyer forever and the right-hand side is the expected payoff from No Send forever. The expression $e_1\Lambda^t$ indicates the distribution throughout all the possible states after t period, and the term $e_1\Lambda^t\rho$ is the probability of meeting a c-type buyer at time t given that the sender is the first to defect at $t = 0$. Due to the fact that the contagious equilibrium requires that the sender should defect after he has defected, he receives payoff 1 if he is matched with a c-type buyer, and gets zero otherwise. This inequality can be simplified to:

$$1-b \geq (1-\delta) e_1 (I - \delta\Lambda)^{-1} \rho , \tag{3}$$

where I denotes the identity matrix with size $n(n+2)\times n(n+2)$. Given that:

$$\begin{aligned}
&(1-\delta)e_1(I-\delta\Lambda)^{-1}\rho+\delta e_1(\Pi-\Lambda)(I-\delta\Lambda)^{-1}\rho \\
&=e_1(I-\delta\Lambda)^{-1}\rho-\delta e_1\Lambda(I-\delta\Lambda)^{-1}\rho \\
&=\sum_{t=0}^{\infty}\delta^t e_1\Lambda^t\rho-\delta\sum_{t=0}^{\infty}\delta^t(e_1\Lambda)\Delta^t\rho \\
&=e_1 I\rho \\
&=1\,.
\end{aligned}$$

Then, we can rewrite (3) as:

$$b\le \delta e_1(\Pi-\Lambda)(I-\delta\Lambda)^{-1}\delta\,.$$

Second, a one-shot deviation from the equilibrium path is unprofitable for the buyer if:

$$\frac{b}{1-\delta}\ge\frac{a}{1-\delta}\,.$$

The left-hand side is the expected payoff for the buyer from Buy forever, and the right-hand side is the expected payoff from No Buy forever. This condition is always satisfied given that $b>a$.

Next, we provided a sufficient condition for a one-shot deviation from an off-the-equilibrium path[7] to make it unprofitable for the buyer under any consistent belief, thus supporting the contagious equilibrium as a sequential equilibrium. Meanwhile, a d-type buyer finds a one-shot deviation from No Buy forever to be unprofitable for any number of d-type senders, denoted by l, if:

$$\frac{a}{1-\delta}\ge\frac{n-l}{n}b+\delta\frac{a}{1-\delta}\,,\quad \forall l=1,2,\ldots,n\,.$$

The left-hand side is the expected payoff from No Buy forever, and the right-hand side is the expected payoff from Buy in the current period as well as No Buy forever from the next period. With probability $(n-l)/n$, she meets a c-type sender and gets b, or with probability l/n, she meets a d-type sender and receives nothing in the current period. Since a d-type buyer has larger incentives to deviate (i.e., Buy) when the number of d-type senders is smaller in the community, the

[7] Refer to Gibbons (1992) for the definitions of "on-the-equilibrium path" and "off-the-equilibrium path."

condition is strongest when $l = 1$; this can then be simplified into inequality (1).

Finally, a one-shot deviation from an off-the-equilibrium path is unprofitable for the sender under any consistent belief. Given that there is at least one d-type buyer and one d-type sender when the d-type sender is currently on the off-the-equilibrium path, any consistent belief for the state $Z_t < n+2$ must be zero. A d-type sender finds a one-shot deviation from No Send forever to be unprofitable given that $Z_t = k$, for all $k = n+2, \ldots, n(n+2)$, if:

$$1 + \sum_{t=1}^{\infty} \delta^t e_k \Lambda^t \rho \geq (1-b) + \delta \sum_{t=1}^{\infty} \delta^t e_k \Pi \Lambda^t \rho .$$

The left-hand side is the expected payoff from No Send forever, and the right-hand side is the expected payoff from Send in the current period as well as No Send forever from the next period. The condition is based on the assumption that the sender meets a c-type buyer in the current period, otherwise, the stage game is over and the sender need not make any decision. Recall that the term $e_k \Lambda^t \rho$ is the probability of meeting a c-type buyer after t periods given that the current state is $Z_t = k$. The inequality can be simplified to:

$$b \geq \delta e_k (\Pi - \Lambda)(I - \delta\Lambda)^{-1} \rho \quad \text{for} \quad k = n+2, \ldots, n(n+2) .$$

This condition is strongest when $k = n+2$. Therefore, we can demonstrate that the following inequality is satisfied:

$$b \geq \delta e_{n+2} (\Pi - \Lambda)(I - \delta\Lambda)^{-1} \rho .$$

By Lemma 1, we arrive at inequality (2).

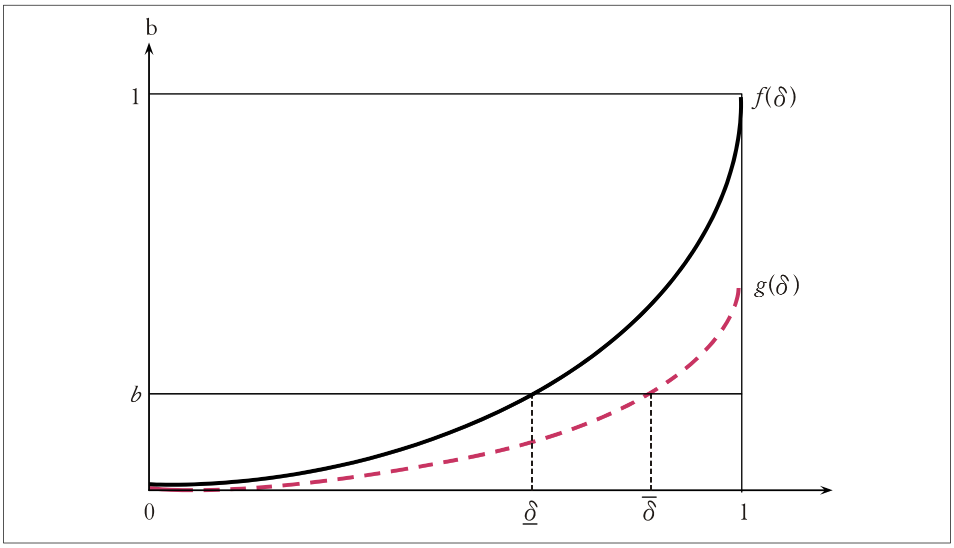
The proof above implies that $0 < \delta e_1 (\Pi - \Lambda)(I - \delta\Lambda)^{-1} \rho < 1$; therefore, we can always choose proper values for a and b, where $0 < a < b < 1$ and Conditions (1) and (2) are satisfied. This completes the proof for Propositions 1 and 2. ■

Although other repeated game equilibria may exist under these conditions, the contagious equilibrium where (But, Send) is the outcome in every period is the most efficient. Thus, our analysis focused on this topic.

There are two comments we can make about this result. First, the existence of the contagious equilibrium critically depends on the existence of the outside option. The concept of contagious equilibrium is based on community enforcement. Players change their partners over time and dishonest behavior against one partner causes sanctions by other members in the society. For the development of a cooperative social norm, this concept requires a harsh punishment scheme. Not only are deviators from the desired behavior punished, but a player who fails to punish is also punished in turn (Kandori, 1992). In the buyer-sender game, the sender has strong incentives to defect. The corresponding cheated buyer (now a d-type) must then defect forever even if she meets a c-type sender. In order to sustain this d-type buyer's incentive to defect in the off-the-equilibrium path, the outside option must be sufficiently high.

Second, Condition (2) implies that the discount factor, δ, has a strong relation with the equilibrium payoff structure. On one hand, we can interpret Propositions 1 and 2, such that for any n, and for any a and b that satisfy Condition (1), we can find the relevant interval of δ that satisfies Condition (2), as shown in Figure 2. This result is in contrast to that of Kandori (1992), which shows that the contagious equilibrium requires δ to be sufficiently large in the prisoner's dilemma game. On the other hand, the interval of b supports the equilibrium changes with the discount factor. The larger the discount factor is, the higher value of b required. Intuitively, in order to make a d-type sender with a higher value in δ defect forever in an off-the-equilibrium path, a deviation from defection must be made less attractive by imposing a higher value on b (and a lower value on $1-b$).

[Figure 2] Graphic Explanation of Proposition 2



The context of buying-selling activities in the electronic market is reinterpreted to see the intuition behind the Propositions more easily. A buyer can choose whether to buy an item in the electronic market at a lower cost or to purchase it in the local store at a higher cost. By choosing to buy in the electronic market, the buyer takes the risk of meeting a dishonest seller who sends an item with inferior quality or does not send the item at all. In order to develop the desirable social norm of trade in the electronic market, the first condition of Proposition 1 implies the importance of the outside option (local store). If the buyer experienced a dishonest seller once in the past, she can then switch from the online market to the local store forever as a punishment to the sellers in the electronic market. If the outside option can provide sufficiently high payoffs to the buyer, this threat is credible and deters dishonest behavior of the sellers. From the perspective of policy makers, in order to develop a healthy and efficient electronic market, the existence of good competitors or alternative markets is required.

The second condition implies two sides of the coin. On one hand, if the current social norm of the electronic market is trust and reciprocity, then no seller has the incentive to initiate dishonesty, since it may destroy the good social norm. In this case, the loss from future business is greater than the benefit from the current deviation if the seller's discount factor is big enough. On the other hand, if the social norm of trust and reciprocity is already deteriorated, the seller who has experienced defection knows that trust and reciprocity in the electronic market may collapse sooner or later according to the contagious process. In this case, he has no incentive to slow down the process by his own honest behavior if the cost of being honest is big enough.

IV. Conclusion

In this paper, we extend Kandori's (1992) theory on contagious equilibrium to the buyer-sender game, showing that the social norm of trust and reciprocity can emerge under a proper payoff structure. According to Kandori (1992), cooperation is possible in the one-sided incentive problem, *only* under local information processing. In contrast, we examine the possibility of cooperative norms in the one-sided incentive environment under the most restricted information structure. Players neither observe the outcomes of games in which they are not involved in, nor recognize the identity of any of their past opponents. The results of this study illustrate the possibility of trust and reciprocity among strangers as an equilibrium behavior based on the concept of social norms and community enforcement.

These results may rationalize many experimental findings on the significant level of trust and reciprocity in the laboratory. Trust and reciprocity are consistent with the rational choices of self-interested players, even when these players are anonymous and randomly change partners each period. However, caution must be taken in experimental design, which intends to examine individual's other related preferences.

Moreover, our random matching model with the buyer-sender game captures important features of online trade through the Internet. Our equilibrium condition shows that attractive outside option is required to sustain the contagious equilibrium. It also implies that in a large economy, the online market may lose its comparative advantage compared with the traditional market in order for the equilibrium to work. Therefore, the contagious equilibrium is more likely to sustain trust and reciprocity in a relatively small community. In a large economy, it may require other mechanisms to help sustain cooperation. The theoretical results by Kandori (1992) as well as the experimental findings by Camera and Casari (2008) also indicate the same idea.

Future research may focus on empirically testing the prediction of the current model. In reality, we observe the social norm of trust and reciprocity in many cases—even between strangers. It is, however, difficult to identify these phenomena as the results of community enforcement or as the outcomes of other institutional effects using field data.

There are also remaining important theoretical questions for future research. The contagious strategy uses the most extreme punishment scheme, and the contagious equilibrium is just one of many equilibria. It would be interesting to know whether or not other strategies with more forgiveness can support trust and reciprocity and whether or not folk theorem is applicable in this setting. Our conjecture is that these questions are difficult to solve under the current information structure. Future research may attempt to understand whether these problems can be solved under other information structure or determine the minimal amount of information to achieve trust and reciprocity.

Finally, one important issue from both the theoretical and empirical perspective is the consideration of the case when different mechanisms coexist and interact with each other. For instance, some buyers follow a strategy that is dependent on information carried by senders, while other buyers tend to follow the contagious strategy. In this case, we can ask whether the reputation system is always effective or the extent to which senders try to build a good reputation. We leave these questions for future research.

Appendix A: Formulas for Matrix Λ, Matrix Π, and Vector ρ

Matrix Λ is an $n(n+2)\times n(n+2)$ transition matrix with elements $\lambda_{ij} = \Pr\{Z_{t+1} = j \mid Z_t = i$, and *all players follow the contagious strategy*$\}$.

Suppose $Z_t^{-1}(i) = (X_i, Y_t) = (p,q)$, and $Z_{t+1}^{-1}(j) = (X_{t+1}, Y_{t+1}) = (r,s)$. Then:

$$\lambda_{ij} = \begin{cases} \dfrac{\dbinom{q}{r-q}\dbinom{n-p}{r-p}(r-p)!\dbinom{p}{p+q-r}(p+q-r)!(n-q)!}{n!}, \\ \textit{if } s=r, p\le r, q\le r, \text{ and } r\le p+q; \\ 0, \quad \textit{otherwise} \end{cases}$$

Matrix Π is an $n(n+2)\times n(n+2)$ transition matrix with elements $\pi_{ij} = \Pr\{Z_{t+1} = j \mid Z_t = i$, *one d-type sender deviates from the contagious strategy,* and *all other players follow the contagious strategy*$\}$.

Suppose $Z_t^{-1}(i) = (X_i, Y_t) = (p,q)$, and $Z_{t+1}^{-1}(j) = (X_{t+1}, Y_{t+1}) = (r,s)$. Then:

$$\pi_{ij} = \begin{cases} \lambda_{ij}, \textit{if } q=0; \\ \dfrac{\dbinom{n-p}{r-p}\dbinom{q-1}{r-p}(r-p)!\dbinom{p}{p+q-r}(p+q-r)!(n-q)!}{n!}, \\ \textit{if } s=r, 1\le p\le r, 1\le q\le r, \text{ and } r\le p+q-1; \\ \dfrac{\dbinom{n-p}{r-p}\dbinom{q-1}{r-p}(r-p)!\dbinom{n-r}{1}\dbinom{p}{p+q-r-1}(p+q-r-1)!(n-q)!}{n!}, \\ \textit{if } s=r+1, 0\le p\le r, 1\le q\le r+1, \text{ and } r\le p+q-1; \\ 0, \quad \textit{otherwise.} \end{cases}$$

where ρ is an $n(n+2)\times 1$ column vector with the ith element equal to the conditional probability for the sender to meet a c-type buyer when the state $Z_t = i$ in period t given by:

$$\rho = (\underbrace{\frac{n}{n},\ldots,\frac{n}{n}}_{n\ elements},\underbrace{\frac{n-1}{n},\ldots,\frac{n-1}{n}}_{n+1\ elements},\ldots,\underbrace{\frac{1}{n},\ldots,\frac{1}{n}}_{n+1\ elements},\underbrace{\frac{0}{n},\ldots,\frac{0}{n}}_{n+1\ elements})^T .$$

Appendix B: Proofs

Proof of Lemma 1 Proof of (i) and (ii):

$$\begin{aligned} f(\delta) &= \delta e_1(\Pi - \Lambda)(I - \delta\Lambda)^{-1}\rho \\ &= \delta \sum_{t=0}^{\infty} \delta^t e_1(\Pi - \Lambda)\Lambda^t \rho \\ &= \delta e_1(\Pi - \Lambda)\rho + \delta^2 e_1(\Pi - \Lambda)\Lambda\rho + \delta^3 e_1(\Pi - \Lambda)\Lambda^2\rho + \cdots, \end{aligned}$$

where $e_1(\Pi - \Lambda)\Lambda^t \rho$ is the difference in the probability of a sender to meet a c-type buyer after t periods when he chooses to defect in the next period and when he chooses to start defection in the current period. Therefore, $e_1(\Pi - \Lambda)\Lambda^t \rho > 0$ for all t, and $\lim_{t\to\infty} e_1(\Pi - \Lambda)\Lambda^t \rho = 0$. So $f(\delta)$ is continuous and increasing over δ, $\lim_{\delta\to 0} f(\delta) = 0$ and $\lim_{\delta\to 1} f(\delta) = 1$. The similar argument applies to $g(\delta)$.

Proof of (iii):

We prove this part by introducing the following notations. We define ω as the random variable whose realization is a pairing of all players in each period and $o_i(t,\omega)$ as player i's opponent in period t for a given realization of ω. The sets $C_B(t,p,q,\omega)$ and $C_S(t,p,q,\omega)$ are defined by:

$$\begin{aligned} &C_B(0,p,q,\omega) = \{p+1, p+2, \cdots, n\}, \\ &C_S(0,p,q,\omega) = \{n+q+1, n+q+2, \cdots, 2n\}, \\ &C_B(t+1,p,q,\omega) = \{i \in C_B(t,p,q,\omega) \mid o_i(t,\omega) \in C_S(t,p,q,\omega)\}, \\ &C_S(t+1,p,q,\omega) = \{i \in C_S(t,p,q,\omega) \mid o_i(t,\omega) \in C_B(t,p,q,\omega)\}. \end{aligned}$$

In the above, $C_B(t,p,q,\omega)$ and $C_S(t,p,q,\omega)$ are the sets of c-type buyers and c-type senders in period t, respectively, when every player plays the contagious strategy. Meanwhile, the sets of players $\{1,2,\cdots,p\}$ and $\{n+1, n+2, \cdots, n+q\}$ are the d-type buyers and d-type senders in period 0, respectively.

Define the set $D(t,\omega)$ by:

$$\begin{aligned} &D(0,\omega) = \{2n\}, \\ &D(t+1,\omega) = D(t,\omega) \cup \{i \mid o_i(t,\omega) \in D(t,\omega)\}. \end{aligned}$$

In the above, $D(t,\omega)$ gives the set of d-type players in period t, such that the sender $2n$ is the only d-type player in period 0. By the definition, $Z^{-1}(1) = (0,1)$ and $Z^{-1}(n+2) = (1,1)$, then:

$$
\begin{aligned}
f(\delta) &= \delta e_1(\Pi-\Lambda)(I-\delta\Lambda)^{-1}\rho \\
&= \delta\sum_{t=0}^{\infty}\delta^t e_1(\Pi-\Lambda)\Lambda^t\rho \\
&= E_\omega\left[\sum_{t=1}^{\infty}\delta^t \Pr(o_{2n}(t,\omega)\in C_B(t,0,0,\omega)\cap D(t,\omega))\right],
\end{aligned}
$$

and

$$
\begin{aligned}
g(\delta) &= \delta e_{n+2}(\Pi-\Lambda)(I-\delta\Lambda)^{-1}\rho \\
&= \delta\sum_{t=0}^{\infty}\delta^t e_{n+2}(\Pi-\Lambda)\Lambda^t\rho \\
&= E_\omega\left[\sum_{t=1}^{\infty}\delta^t \Pr(o_{2n}(t,\omega)\in C_B(t,1,0,\omega)\cap D(t,\omega))\right].
\end{aligned}
$$

We show that:

$$
\begin{aligned}
&E_\omega\left[\sum_{t=1}^{\infty}\delta^t \Pr(o_{2n}(t,\omega)\in C_B(t,0,0,\omega)\cap D(t,\omega))\right] \\
&\quad\geq E_\omega\left[\sum_{t=1}^{\infty}\delta^t \Pr(o_{2n}(t,\omega)\in C_B(t,1,0,\omega)\cap D(t,\omega))\right],
\end{aligned}
$$

by showing that the inequality holds for every realization of ω, that is:

$$
\begin{aligned}
&\sum_{t=1}^{\infty}\delta^t I(o_{2n}(t,\omega)\in C_B(t,0,0,\omega)\cap D(t,\omega)) \\
&\quad\geq \sum_{t=1}^{\infty}\delta^t I(o_{2n}(t,\omega)\in C_B(t,1,0,\omega)\cap D(t,\omega)).
\end{aligned}
\tag{4}
$$

In the above, the notation $I(\Psi)$ indicates a function equal to one or zero depending on whether the deterministic condition Ψ is true or false.) The definition of C_B implies that:

$$C_B(t,1,0,\omega)\subset C_B(t,0,0,\omega),$$

so

$$C_B(t,1,0,\omega)\cap D(t,\omega)\subset C_B(t,0,0,\omega)\cap D(t,\omega),$$

and the inequality (4) gives the desired result. ■

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