“Confidentially yours”: Restricting information flow between trustees enhances trust-dependent transactions

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Abstract

By extending the traditional trust game to settings involving more than one trustee, we study how restricting information flow between trustees influences trust and reciprocity. We start with a theoretical investigation and then report the results of two experiments designed to examine investor strategy and trustee behavior. Our results suggest that, compared to when information flow is unrestricted, restricting information flow between trustees leads to the following: (a) total investment is larger, (b) the number of trustees receiving positive investment is about the same, and (c) the investor sends out a larger variety of invested amounts to different trustees.

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1. Introduction

This study is motivated by the observation that economic agents often seek to build simultaneous trusting relationships with many other agents. Whereas most previous research has focused on trust and reciprocity in a one-to-one setting, here we extend the study to the one-to-many scenario. For example, a firm may give discounts to a portion of customers to cultivate loyalty, although it cannot give discounts to all its customers at the peril of its profit margins. Moreover, discounts or other forms of relationship building gestures do not guarantee future benefits; much depends on the reciprocating propensity of the receiving agents.

Previous studies have shown that communication in a bilateral interaction (even if the subject of the communication is irrelevant to the issues being negotiated) enhances the development of trusting relationships (Valley et al., 1998; Buchan et al., 2006). In the context of an agent building trusting relationships with many others, a related question asks what happens if those others are allowed to communicate between themselves the amount of benefit they receive from the relationship-building agent. The extent of information flow between receivers may vary from case to case. In some types of buyer–supplier contracting, for example, the transacting parties are bound by the contract terms not to disclose deal

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Our main objective is to study how information flow influences the amount and distribution of resources invested in relationship building in the one-to-many setting. We attempt to abstract the relationship-building aspects of the above-mentioned examples into a setting involving a trusting agent and a number of potentially reciprocating agents to study agent behavior in this setting through an extension of the trust game or investment game first proposed by Berg et al. (1995). In the original trust game, an investor can choose to donate any part or none of an endowment to a trustee. The donation is tripled when it reaches the trustee, who then decides upon sending back an amount (or not sending any amount) to the investor. After this, the game, in the one-shot version, ends. Both players are anonymously and randomly matched. Trust and reciprocity are said to be observed in the sense that players seldom follow the subgame perfect equilibrium strategy of not giving any money to the other party and trustees often reciprocate positively.

Our extension follows Berg et al.’s basic settings except that the number of trustees becomes $N > 1$. We consider (a) investors’ strategy in deploying investments, and (b) trustees’ responding behavior, under conditions that vary in two parameters: the value of $N$ and the information condition under which every trustee either knows the amount of investment received by every other trustee (the public information condition) or knows only the amount received by herself (the private information condition). When information flow between trustees is restricted in this sense, we propose that, if the investor considers her task based on a simplified, “baseline” model of expected trustee reciprocity, the optimal strategy of a risk-neutral investor is, in general, to send positive investment packages at no more than two different levels to some (but not necessarily all) of the trustees, while the remaining trustee(s) receive nothing. We then investigate the effect of non-baseline concerns including investor risk aversion and, under the public information condition, (a) how reciprocity is influenced by uneven distribution of investments, (b) trustees free riding on the moral obligation to reciprocate, and (c) distributional fairness. In our theoretical development, we argue that the basic characteristics of the investor’s optimal strategy in the baseline model would be preserved even if these additional concerns are included. We then report the results of two experiments designed to investigate investor strategy and trustee behavior. Both theoretical reasoning and experimental evidence suggest that, compared with the public information condition, when information flow between trustees is restricted, (a) total investment is larger, (b) the number of trustees receiving non-zero investment is about the same, and (c) the investor sends out a larger variety of invested amounts to different trustees.

2. Research framework

A useful and relatively tractable abstraction to study the one-to-many trust-reciprocity scenario, with reputation effects being filtered out, is the one-shot, $N$-trustee investment game with random and anonymous matching. In such a game, apart from considering the reciprocating capacity of each trustee solely with respect to the benefit she receives from the investor, the investor also needs to consider how trustees would react to unequal investments among them. Fairness therefore becomes a more complicated matter than in the simple one-to-one trusting situation. In fact, distributional fairness can come in three guises here: (a) distributional fairness between the investor and any one trustee based on the exchanges between the two of them, (b) fairness in distributing investments among trustees, (c) distributional fairness among all the players based on all the exchanges. Players in the one-to-one trust game would only possibly consider (a).

Moreover, if a trustee knows that other trustees have received investment from the investor, the trustee may feel that other people could fulfill her reciprocity responsibility for her. This is related to the “diffusion of responsibility” phenomenon well documented in the helping literature in social psychology (e.g., Darley and Latane, 1968). It may undermine the reciprocating tendency of any trustee and can be seen as the trustee “free riding” on the moral obligation to reciprocate. This will in turn undermine the trusting capacity of the investor, and hence the invested amounts.

Our focus in this study is on how changes in the information condition influence a number of dependent variables. Operationally, a distinction can be made between the case when the trustees all know how much every other trustee has received before deciding on how much to reciprocate (we call this case the “public information” condition), and the case when a trustee knows only how much she has received before making the decision (we call this case the “private information” condition). Although information condition manipulation can come in many forms, we shall study only this manipulation here, with all other aspects of the game as common knowledge.

In subsequent sections, we develop hypotheses regarding investor strategy and trustee behavior. We lay out a simple baseline model as an initial theoretical approach to the investor strategy problem; then, we consider additional factors not included in the model and consider how such factors influence the optimal strategy. After the theory discussion, we report the results of two experiments that test our hypotheses. The report ends with a concluding section in which further development is suggested.

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2 An investment portfolio has one level if all the investments are equal, two levels if all the investments are either one of two different amounts, and similarly for higher levels. Zero-amount investments are considered to be a level.

3 Note that the public nature of the information refers only to the amount the investor sends to each trustee. In both the public and private information conditions, trustees are not informed of the reciprocated amounts (if at all) of other trustees.
3. A baseline decision-analytic model of investor behavior under the private information condition

The setting of the game is that there is one investor, \( S \), and \( N \) trustees. All players are randomly and anonymously matched. At the beginning of the game, \( S \) has an endowment \( w \), while the trustees have no endowment. In stage 1 of the game, \( S \) decides to send amount \( x_i \) to trustee \( i, i = 1, 2, \ldots, N \), under the following constraints:

\[
\begin{align*}
    w &\geq \sum_{i=1}^{n} x_i \\
    x_i &\geq 0, \quad i = 1, 2, \ldots, N.
\end{align*}
\]

Each \( x_i \) is multiplied by a ratio \( \beta (=3 \text{ in the experiment in Berg et al. and also the experiments reported here}) \) when it reaches \( i \), who, in stage 2 (the last stage) of the game, sends back an amount \( y_i \) to \( S \) subject to this constraint:

\[
\beta x_i \geq y_i \geq 0, \quad i = 1, 2, \ldots, N.
\]

Note that all trustees make their decisions simultaneously and without communication.

We now assume (for this model only) that the investor believes that, given the \( x_i \)s and other exogenous parameters, the \( y_i \)s are random variables that are independently distributed across \( i \) and are such that

\[
E(y_i) = f(x_i | w, \text{INF}, N, \beta), \quad i = 1, 2, \ldots, N,
\]

where \( \text{INF} \) denotes the information condition. Since \( w \) and \( \beta \) are kept constant in our experiments, and, as will be discussed, this model is completely valid only under the private information condition, we simplify notation and write \( E(y_i) = f(x_i) \), bearing in mind that \( f \) may vary with \( N \). Note that, since trustees are anonymously matched to \( S \), the functional form \( f \) should be identical across \( i \). It is also obvious that \( f(0) = 0 \).

The above expression as a representation of \( S \)'s belief is certainly valid under the private information condition, when \( S \) can safely assume that any \( i \)'s decision on reciprocity will not be influenced by the other trustees' actual received amounts simply because such information is not available to \( i \). It is also a flexible expression capable of capturing any factors that \( S \) believes will influence \( i \)'s decisions, such as positive reciprocity, fairness concern between \( i \) and \( S \), and other factors.\(^4\) Note that if the information is public, \( S \)'s belief of \( E(y_i) \) potentially will not be a function of \( x_i \) only since \( S \) might believe that \( E(y_i) \) can be affected by how much other trustees have received. We shall come back to this point in subsequent sections.

We then proceed under three further assumptions: (a) \( S \) is risk neutral, (b) following Chaudhuri and Gangadharan (2007) and Gneezy et al. (2000), \( S \) is trusting mainly because of the expectation of reciprocity, and (c) \( f(x) \) is non-decreasing in \( x \) (Pillutla et al., 2003). As a result, \( S \) will seek the strategy that gives the maximum expected net payoff; such a strategy will be the solution of the following optimization program:

\[
\max_{x_i} \left\{ w - \sum_{i=1}^{n} x_i + \sum_{i=1}^{n} f(x_i) \right\} \quad \text{subject to} \quad \sum_{i=1}^{n} x_i \geq 0, \quad x_i \geq 0, \quad i = 1, 2, \ldots, N.
\]

The Kuhn–Tucker solution of this problem suggests that if \( S \) sends out a positive investment to a trustee \( i \), the value of this positive investment, say \( \delta_i \), satisfies the following conditions (where \( \mu \) is a constant, non-negative Lagrange multiplier that does not vary with \( i \)):

\[
\begin{align*}
    f'(\delta_i) &= \mu + 1 \geq 1, \\
    f'(\delta_i) &\geq f'(0) \quad \text{if } \exists x_i = 0 \text{ in the optimal solution,} \\
    0 &< \delta_i \leq w, \\
    \mu \left( w - \sum_{i : x_i > 0} \delta_i \right) &= 0.
\end{align*}
\]

The first two conditions immediately suggest that if \( f(\cdot) \) is strictly concave, then either all trustees receive nothing (i.e., \( S \) plays the subgame perfect equilibrium strategy) or everyone receives a positive amount. If \( f(\cdot) \) is strictly convex, \( \delta_i \) has only

\(^4\) Under the private information condition, \( S \) may also believe that \( i \) will form beliefs with regard to how much other trustees have received based on the experiment's setting (which is common knowledge) and \( x_i \). \( S \) may then further believe that \( i \) will take into account such beliefs when deciding how much to send back. For example, given a certain positive \( x_i \), \( S \) may believe that \( i \) will suspect that other trustees have received investments also and hence will have a weaker tendency to reciprocate (due to diffusion of responsibility) compared with the case when such suspicion does not come into \( i \)'s mind. All these concerns could interact in a complicated manner, but in effect they can all be absorbed into \( f(\cdot) \) as a representation of \( S \)'s “theory of the mind” of the trustees, given the private information condition.
one possible value. In fact more detailed consideration reveals that if \( f(w) > w \), the optimal solution will be to send the full endowment to exactly one of the trustees (i.e. \( \delta_i = w \)).

If \( f(\cdot) \) is linear, say \( f(x) = bx_0 \), then, depending on whether \( S \) believes she will be reciprocated with more or less than her investment on average (i.e. whether \( b > 1 \) or \( b < 1 \)), \( S \) will either send out nothing or all of the endowment. In the latter case, it can be easily seen that the optimal investment portfolio is degenerate (i.e., all combinations that use up the full endowment are equally optimal). This is a natural consequence of risk neutrality and a linear \( f(\cdot) \).

However, in general, the Kuhn–Tucker solution implies that \( \delta_i \) may take on multiple positive values as long as \( f'(\delta_i) \) remains the same for all those positive values, while the number of trustees receiving positive investment may be between 1 and \( N \).

One of the major assumptions in the above model is risk neutrality. This can be justified based on Eckel and Wilson’s (2004) findings that risk preferences do not play a major role in the decision to trust. Nevertheless, in pursuing the decision-analytic spirit of our baseline model, we need to allow for risk aversion. The calculation is, of course, more complicated. We can start with viewing the whole investment action as participating in a compound lottery. It can be shown that if we assume that \( y_i \) is a random variable the distribution of which is conditioned on \( x_i \) but not on other \( x_j \)s with \( j \neq i \) (this is true under the private information condition), then, at optimum, all non-zero \( x_j \)s satisfy the following integral equation:

\[
\int \left( -u'(w + \sum_k (y_k - x_k))p(y_i, x_i) + u[w + \sum_k (y_k - x_k)]p'(y_i, x_i) \prod_{j \neq i} [p(y_j, x_j) dy_j] \right) = \mu,
\]

where the integration is only over the \( j \)'s for which \( x_j > 0 \), \( u(\cdot) \) is the Bernoulli utility function of the investor, \( \mu > 0 \) is a Lagrange multiplier (constant across \( i \)), \( p(y_i, x_i) \) is the probability density function of \( y_i \) given \( x_i \) as believed by the investor, and \( p'(y_i, x_i) \) is the partial differentiation of \( p(y_i, x_i) \) with respect to \( x_i \). A solution is that all non-zero \( x_i \)s are the same, although we expect, in general, multiple but probably discrete non-zero \( x_k \) solutions for a particular \( \mu \).

In a special case, \( S \) believes that \( e_i = (y_i/x_i) \) are identically and independently distributed random variables (in which case \( f(\cdot) \) would be linear) so that we can apply Rothschild and Stiglitz’s (1971) diversification theorem and conclude that \( S \) will invest equally among all the trustees (though not necessarily invest the full endowment).

3.1. Investor hypothesis under the private information condition

As a final stage of hypothesis development for the private information condition, we introduce a “simple belief” assumption, namely that \( S \)'s “theory of the mind” of the trustees is not so complicated as to result in a non-linear \( f(\cdot) \) with more than one inflection point (where \( f'(x)=0 \)) within \( 0 \leq x \leq w \). This, together with the assumption that \( S \) is self-utility maximizing, risk neutral and holds non-linear \( f(\cdot) \) (so that the Kuhn–Tucker solution is not degenerate) allows us to hypothesize that there can be at most two different possible levels of \( \delta_i \) (positive investments) in \( S \)'s investment portfolio. Moreover, if \( S \) is risk averse and believes that \( e_i = (y_i/x_i) \) are identically and independently distributed, we also know from the diversification theorem that there can be only one non-zero level of investment. We therefore propose to test experimentally the following hypothesis.

**Investor hypothesis 1 (strategy under the private information condition).** Under the private information condition, the investor’s portfolio comprises at most three levels of investment including zero.

For example, an investment portfolio of \( \{30, 20, 10, 10, 0, 0, 0, 0\} \) among eight trustees violates the hypotheses because it comprises four levels of investment, whereas the allocation \( \{40, 10, 10, 10, 0, 0, 0, 0\} \) does not violate the hypothesis because it comprises three levels of investment.

4. Relaxing the baseline assumptions

4.1. Distributional fairness as a concern of the investor

In the baseline model, we assume that the investor is trusting because of the expectation of reciprocity (Chaudhuri and Gangadharan, 2007; Gneezy et al., 2000). However, we may need to allow for the possibility that investors are also concerned about distributional fairness (Cox, 2002), but as far as Investor hypothesis 1 is concerned, distributional fairness does not change the basic prediction that the investor’s portfolio consists only of a limited number of levels of investment. An investor strongly driven by distributional fairness will simply send out equal amount of investments to all the trustees since they are all symmetrically anonymous to her. This is true no matter what the information condition is. For example, under the private information condition, if a risk neutral investor believes that she is as much entitled to a “fair share” as the trustees, she may choose to send an amount of \( x \) to each trustee, where \( x \) solves:

\[
w - Nx + Nf(x) = \beta x - f(x),
\]

under the constraint \( Nx \leq w \). The above should be replaced by an expected utility expression if the investor is risk averse, but whatever the real calculation may be, a strong distributional fairness concern will not affect Investor hypothesis 1 since the portfolio will then comprise only one level of investment.
It is also obvious that, because of anonymity, the gist of the above discussion on investor strategy holds under the public information condition.

4.2. Marginal benefit versus cost as a concern of the investor

Following the reasoning of Bolton et al. (1998), an investor may think that a positive investment needs to give as much marginal benefit to the trustee as marginal cost to the investor. For example, distributing $30 equally among ten trustees may not generate as much welfare as distributing the same amount equally between two trustees since, as Bolton et al. suggest, the impact of $3 to a trustee is less than one-fifth the impact of $15 to the same trustee. Therefore, the investor will also feel a “pull” towards concentrating her investment despite fairness concerns. Suppose this means that the investor decides to send out a minimum amount of $v$ to any trustee who receives a positive amount and $v \geq x$, with $x$ being the solution of the equation in the last subsection. Then, as a trade off between distributional fairness and marginal benefit concerns, the investor could send out packages of $v$ to $r$ trustees where $r$ solves:

$$w - rv + rf(v) = \beta v - f(v),$$

under the constraints $r \leq N$ and $rv \leq w$. The remaining $N - r$ trustees receive nothing from the investor. This results in an investment portfolio with two levels of investment, which is also consistent with Investor hypothesis 1.

5. Behavioral hypotheses

5.1. The public information condition

Under the public information condition, where each trustee knows how much the investor $S$ sends each and every one of the trustees, the central assumption of the previous baseline model is not valid: $S$ will probably not believe that the distribution of $y_i$ is conditional on $x_i$ only, not on the amounts received by other trustees. We shall now examine the various concerns that come into play under the public information condition (they also come into play under the private information condition, but in the form of suspicion, which, as mentioned, can be absorbed into the single-argument function $f(x_i)$).

When $N > 1$ and under the public information condition, there are a number of factors influencing a trustee’s reciprocating decisions that are not present when she is the only trustee in an $N = 1$ game. Some of those factors will lead to a greater propensity to reciprocate while others undermine that propensity. It may also happen that the same fact (for example, when a trustee who has received a positive investment sees that another trustee has received nothing) potentially leads to conflicting effects on the propensity to reciprocate because such a setting may be conducive to multiple interpretation of the relevant social norms of behavior. In the next two sections, we shall focus on two of those factors that we think are important in this context. We shall lay out hypotheses describing experimentally feasible conditions under which we expect those factors to become dominant over other factors so that we can investigate them in a laboratory setting.

5.1.1. A hypothesis on trustees’ reaction to unequal investments

Let $i$ and $j$ be the two trustees in an $N = 2$ game. Suppose $x_j > x_i = 0$, and this is known to both $i$ and $j$ (i.e. the game is under the public information condition). The following could happen:

1. $j$ sees that she has received more than $i$, feels grateful towards $S$, and sends back more than if she had been the only trustee, or
2. $j$ sees that the two of them have received unequal amounts, feels that $S$ is behaving discriminatorily, and sends back less than if she had been the only trustee.

Consequences 1 and 2 have opposite impacts on $j$. However, note that it is common knowledge that the investor does not know the trustees’ identities. Any difference in investment between trustees is bound to be interpreted by the favored trustee as a non-personal random act of kindness. As such, the sense of personal gratitude can be inhibited. On the other hand, the discriminatory act itself is not random; it is an explicit strategic choice to distribute investments unequally. If it sets a norm of unfair behavior, it is likely to be followed. Hence, to put it conservatively, we expect that consequence 2 has at least the same impact on $j$ as consequence 1, if not more. As a result, we hypothesize that

Trustee hypothesis 1 (reaction to unequal allocation of investment). When $N = 2$, under the public information condition, if a trustee receives a positive amount and knows that the investor has sent nothing to the other trustee, she sends back no more than if she had been the only trustee.

Trustee hypothesis 1 is formulated narrowly to the case where the total investment is fixed. In more general cases, we believe that trustees’ reaction to unequal allocation will be in line with the argument behind this hypothesis so that if an

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5 Note that “reciprocate” is used in this paper, unless otherwise stated, in the behavioral sense of sending money back to the investor. A trustee may “reciprocate” while actually acting out of unconditional kindness.
unequal allocation of investment (with this fact alone) has any impact at all on a trustee’s propensity to reciprocate, it is to underestimate that propensity, whether the trustee is on the favored or un-favored side of the unequal allocation. However, when the total investment is allowed to vary, as is discussed in the next section, other considerations may play a role in determining the propensity to reciprocate.

5.1.2. Free riding on the moral obligation to reciprocate

Suppose \( N = 2 \), the game is under the public information condition, and \( x_i > 0 \). What would be the change in \( j \)'s reciprocated amount when \( x_i \) increases from zero to a positive amount \( \Delta x_i \) that is still smaller than \( x_j \)? The following could happen:

1. The unfairness in distribution of investment is less when \( x_i = \Delta x_i \) compared with when \( x_i = 0 \), and \( j \) therefore sends back more in the former than in the latter case. We moreover expect that, for a given \( \Delta x_i \), this aspect of its impact on \( j \)'s reciprocity is less the larger \( x_j \) is because the relative change in unfairness (which would be an increasing function of a controlling variable of the form \( (x_j - x_i)/x_j \)) is correspondingly less.

2. The total investment \( =x_i + x_j \) is higher when \( x_i = \Delta x_i \) compared with when \( x_i = 0 \), so that \( j \), seeing that the investor has greater “overall trust” in the former than in the latter case, sends back more correspondingly. Again, we expect that, for a given \( \Delta x_i \), this aspect of its impact on \( j \)'s reciprocity is less the larger \( x_j \) is because the relative change in total investment is correspondingly less.

3. It is well documented in the helping literature in social psychology, such as Darley and Latane, that when other people are also present in a situation that one is facing, one feels less personally responsible for that situation. A similar kind of “diffusion of responsibility” may also happen in the scenario we are considering. When \( x_i = \Delta x_i \), compared with when \( x_i = 0 \), \( j \) may feel that she can “free ride” on \( i \) for the moral obligation to reciprocate and thus sends back less in the former than in the latter case. We also expect that, for a given \( \Delta x_i \), this aspect of its impact on \( j \)'s reciprocity is largely independent of \( x_j \), because \( j \)'s perceived free riding opportunity should not be related to her own received investment but only on the amount sent to the other player. The higher this amount, the higher the opportunity to free ride on the moral obligation to reciprocate.

To summarize, impacts 1 and 2 lead to an increase in \( j \)'s reciprocated amount when \( x_i = \Delta x_i > 0 \) compared with when \( x_i = 0 \), while impact 3 leads to the opposite effect. We also expect that, given \( \Delta x_i \), impacts 1 and 2 diminish as \( x_j \) increases, while impact 3 should not be affected by \( x_j \). Thus, as long as it is permitted by the endowment constraint, when \( x_j \) is sufficiently large compared with \( \Delta x_i \), impact 3 will become the dominant impact or at least be large enough to counterbalance the other two effects. Therefore we state the following hypothesis:

**Trustee hypothesis 2 (moral obligation free riding).** When \( N = 2 \), under the public information condition, given \( x_i > 0 \), the amount sent back by \( j \) when \( x_i = \Delta x_i > 0 \) is no more than when \( x_i = 0 \), provided that \( x_j \) is sufficiently large compared with \( \Delta x_i \).

As with Trustee hypothesis 1, Trustee hypothesis 2 is formulated specifically for experimental testing. In more general cases, applying a similar line of argument as described earlier, we believe that if trustee \( j \)'s received investment is sufficiently larger than trustee \( i \)'s, then, all else being equal, the reciprocated amount of \( j \) will be decreasing in \( x_i \) due to the dominant impact of moral obligation free riding.

5.2. Effect of information condition on investment

Under the private information condition, a trustee may form beliefs (based on how much she has received) regarding the investor’s portfolio (i.e. how much the other trustees have received) and may have her reciprocating propensity undermined by beliefs that suggest unfair distribution of investment or high opportunity of moral obligation free riding. While the investor may therefore adjust her investment on any particular trustee in order to influence that trustee’s beliefs, the real portfolio itself does not necessarily reflect explicit consideration for fairness and moral obligation free riding since it is not publicly known among the trustees. For example, each trustee may make inference (based on how much she has received) on whether the real portfolio is a fair distribution; in fact, even if the investor did so, the trustees would not know.

By contrast, under the public information condition, the real investment portfolio is common knowledge among all the players. We therefore expect that, under the public information condition, the investment portfolio more strongly reflects consideration for such factors as distributional fairness and trustees’ inclination towards moral obligation free riding than under the public information condition.

Next, we argue that the investor is less concerned with overall trust than with distributional fairness and moral obligation free riding when designing her investment portfolio under the public information condition. This is because any potential

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6 This statement can be formally rephrased as \( \partial y_j / \partial x_i \big|_{\text{overall trust}} < 0 \), at least in the range of investments applicable to Trustee hypothesis 2, where \( y_j \) indicates \( j \)'s reciprocated amount and the differentiation is only taken with regard to the impact of overall trust.

7 Investors can “reveal” unequal allocation to one trustee by sending, for example, more than half of the endowment to him/her. However, there is no way to “reveal” equality of distribution.
decrease in reciprocated amount due to a decrease in total investment (i.e. a decrease in overall trust) is offset by a corresponding increase in the money that the investor keeps for herself. This last insight can be illustrated as follows: In the case of $N = 1$, using the notations in Section 3, a decrease in investment on trustee $i$ from $x_i$ to $x_i - \Delta x_i$ ($\Delta x_i > 0$) leads to a change in overall expected payoff that is equal to $-(f(x_i) - 1)\Delta x_i$, rather than just $-f(x_i)\Delta x_i$. Empirically, $f(\cdot)$ has been found to be around one in $N = 1$ trust game experiments (e.g. Cox); if we believe that this magnitude is generally realistic, then $|f(x_i) - 1|\Delta x_i$ must be substantially smaller than $f(x_i)\Delta x_i$.

When $N > 1$, we expect the investor to realize that any change in overall trust is similarly offset by an opposite change in the money she keeps for herself. However, there is no such offset mechanism if the investor allocates her investment more unequally among trustees or provides more opportunity for trustees to free ride the moral obligation to reciprocate, controlling for her total investment (i.e. overall trust). Hence we expect that the concern for fairness and moral obligation free riding to be the dominant factors that influence investment portfolio under the public information condition.

One of the immediate consequences is that the investor will decrease her investments to trustees who would have received positive investment under the private information condition if the information condition is in fact public. This is to keep at low level the trustees’ propensity for moral obligation free riding; it can also mitigate the inequality between trustees receiving positive investment and trustees receiving no investment (if any).

Next, we consider how the number of trustees receiving positive investment changes across information conditions. Since concern for fairness is more explicit in the portfolio under the public compared with the private information condition, we may expect more trustees receiving the (same) positive investment in the former than in the latter condition. However, concern for moral obligation free riding is also more explicit under the public information condition, which should then lead to fewer trustees receiving positive investment. If these two effects approximately balance each other, we should find that the number of trustees receiving positive investment is not significantly different under the two information conditions. While acknowledging that there is no strong theoretical reason to support this conjecture, we here formulate it as part of a hypothesis to be tested through experimentation.

Since the average investment for trustees receiving positive amounts is expected to be higher under the private than under the public information condition while the number of such trustees is hypothesized to remain the same, we further hypothesize that total investment will be higher under the private information condition. To summarize:

**Investor hypothesis 2 (effect of information condition on total investment).** Compared with the public information condition, under the private information condition: (a) total investment is higher, and (b) the number of trustees receiving positive investment is the same.

As suggested earlier, the portfolio should more explicitly reflect a concern for distributional fairness under the public than under the private information condition. Thus the number of levels of investment will be smaller under the public than under the private information condition. Recall that we hypothesized that, under the private information condition, the investor’s portfolio will comprise at most three levels of investment including zero (Investor hypothesis 1). We shall therefore test the hypothesis that the levels of investment will be fewer under the public information condition; that is,

**Investor hypothesis 3 (strategy under the public information condition).** Under the public information condition, the investor’s portfolio comprises at most two levels of investment including zero.

We report below the results of two experiments designed to test our hypotheses. Experiment 1 was designed to test the Investor hypotheses, and Experiment 2 was designed to test the Trustee hypotheses.

6. Experiment 1: investor strategy

6.1. Method

6.1.1. Subjects

Seventy undergraduate subjects at the Hong Kong University of Science and Technology, 26 in the role of investors and 44 in the role of trustees, participated in the experiment. All subjects volunteered to take part in a decision making experiment with payoff contingent on performance.

6.1.2. Design

Denote the private information condition as INF0 and the public information condition as INF1, and further denote the games in the form INFxNy, such that, for example, INF02 means a game with private information and two trustees, while INF1N8 means a game with public information and eight trustees. Since information condition is irrelevant when $N = 1$, we denote the standard one-to-one trust game as N1. With this coding, the seven treatment conditions in our experiment are: N1, INF02, INF04, INF08, INF12, INF14 and INF18. The latter six can be organized into a 2(INF0 vs INF1) × 3(N = 2, 4, 8) within-subject design. In all the games, each investor had an endowment of HK$50 (1US$ = HK$7.8)\(^8\) while the trustees had no endowment. Any investment by the investor was tripled when it reached the trustee. All other information about

\(^8\) All monetary amounts are in HK$ unless otherwise stated.
the game was common knowledge in all conditions. In addition to earnings from the actually played game, each subject was paid a show-up fee of $10 at the end of the session. Not including the show-up fees, average investor payoff was $35.46 and average trustee payoff was $46.32 in this experiment.

### 6.1.3. Procedure

Subjects were randomly divided into investors and trustees (neutral terms were used in the instructions). The strategy method was used on the investors' side. That is, each investor was asked to decide how to invest in the above-mentioned seven games varying by information condition and number of trustees; in the end, only one of those games was actually played with randomly and anonymously matched trustee(s).

Each session comprised three stages. All subjects were given a general instruction describing the structure of the game. In stage 1, the investors were asked to write down their decisions in all seven games. The various conditions were presented in either of two counterbalanced orders with reference to the information condition:

**Order a:** N0 → INF0N2 → INF0N4 → INF0N8 → INF1N2 → INF1N4 → INF1N8;

**Order b:** N0 → INF1N2 → INF1N4 → INF1N8 → INF0N2 → INF0N4 → INF0N8.

In stage 2, every trustee was informed about which game she would actually play, and was given the decision of the investor with whom she was matched (only the decision for the actually played game was given). The trustees were then asked to decide how much to reciprocate (if at all).

In stage 3, all players had their payoffs plus show-up fees confirmed and paid by the coordinator and were then dismissed.

### 6.2. Results

#### 6.2.1. Order of presentation

The seven games were presented to investors in either of two orders that were counterbalanced in terms of which information condition was presented first (note that N0 was always presented before all others). Our analysis shows that order has no significant main effect or interaction effect with other independent variables on total investment, number of trustees receiving positive investment, and the level of investments (except for a significant order × INF × N interaction on total investment, $F(2, 48) = 3.73, p < .05$, which does not affect our major conclusions). In what follows, the data are collapsed across both orders.

#### 6.2.2. Total investment

Table 1 presents the average total investment in the various experimental conditions. The mean investment under $N = 1$ ($27.54$) is significantly smaller than the mean total investment under all other conditions, $t(25) = 4.90$, $p < .0001$, but is significantly larger than zero, $t(25) = 7.63$, $p < .0001$. The latter result is consistent with other investment game findings.

Consistent with Investor hypothesis 2, total investment is higher under the private compared with the public information condition, $F(1, 25) = 5.13$, $p < .05$, and this is true for all $N$ (except, of course, for $N = 1$). That is, total investment or “trust-dependent transaction” is enhanced when information flow between trustees is restricted.

In addition, total investment increases with $N$, $F(2, 50) = 12.35$, $p < .001$. While we have not offered any hypotheses on this issue, it should be noted that the number of trustees receiving a positive investment in fact increases with $N$ (to be discussed in the next subsection) while more detailed analysis shows that the average investment among those receiving positive investment fluctuates with $N$ without following a monotonic trend. Therefore, the overall increase in total investment with $N$ is largely driven by the increase in the number of trustees receiving a positive amount. The INF × N interaction is not significant, $F(2, 50) = 0.02$, $p = .98$.

### Table 1

Average (S.D.) total investment in $ (Experiment 1).

<table>
<thead>
<tr>
<th>Information condition</th>
<th>N = 1</th>
<th>N = 2</th>
<th>N = 4</th>
<th>N = 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private (INF0)</td>
<td>27.54 (18.39)</td>
<td>36.31 (16.89)</td>
<td>38.73 (16.37)</td>
<td>41.62 (14.65)</td>
</tr>
<tr>
<td>Public (INF1)</td>
<td></td>
<td>33.62 (16.64)</td>
<td>35.85 (16.10)</td>
<td>39.15 (16.05)</td>
</tr>
</tbody>
</table>

### Table 2

Average number (proportion) of trustees receiving positive investment (Experiment 1).

<table>
<thead>
<tr>
<th>Information condition</th>
<th>N = 2</th>
<th>N = 4</th>
<th>N = 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private (INF0)</td>
<td>1.54 (0.77)</td>
<td>2.69 (0.67)</td>
<td>5.58 (0.70)</td>
</tr>
<tr>
<td>Public (INF1)</td>
<td>1.69 (0.85)</td>
<td>3.04 (0.76)</td>
<td>5.88 (0.74)</td>
</tr>
</tbody>
</table>
Table 3 Average (S.D.) number of investment levels (Experiment 1).

<table>
<thead>
<tr>
<th>Information condition</th>
<th>N=2</th>
<th>N=4</th>
<th>N=8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private (INF0)</td>
<td>1.54 (0.51)</td>
<td>2.08 (0.84)</td>
<td>2.31 (1.44)</td>
</tr>
<tr>
<td>Public (INF1)</td>
<td>1.19 (0.40)</td>
<td>1.50 (0.65)</td>
<td>1.62 (0.75)</td>
</tr>
</tbody>
</table>

6.2.3. Number of trustees receiving positive investment

Table 2 shows the mean number of trustees receiving positive investment across conditions. Consistent with Investor hypothesis 2, the number of trustees receiving positive investment remains approximately the same under different information conditions, \( F(1, 25) = 1.2, p = .28 \).

We also observe a main effect of \( N \), \( F(2, 50) = 66.25, p < .0001 \). More detailed analysis shows that there is also a mild effect of \( N \) on the proportion of trustees receiving positive investment, \( F(2, 50) = 2.93, p = .074 \).

6.2.4. Number of investment levels

Table 3 presents the number of investment levels, denoted for discussion here as \( L(N, INF) \), under different conditions (e.g., if \( N=4 \), \( INF=0 \) and the investment portfolio is \( \{30, 10, 10, 0\} \), then \( L(4, 0) = 3 \) since the investment consists of 3 levels: 30, 10, and 0). Consistent with Investor hypothesis 1 (which predicts \( L(N, 0) \leq 3 \)), non-parametric Sign tests show that \( L(N, 0) \leq 3 \) for \( N=4 \) (\( p < .0001 \)) and 8 (\( p = .0009 \)). Similarly, consistent with Investor hypothesis 3 (which predicts \( L(N, 1) \leq 2 \)), Sign tests show that \( L(N, 1) \leq 2 \) for \( N=4 \) (\( p = .002 \)) and 8 (\( p = .03 \)). Moreover, except for \( I(2, 1) \) (where Sign test for \( L > 1 \) has \( p = .06 \)), Sign tests show that \( 1 < L(N, 0/1) \) at \( p \leq .001 \), suggesting that in general investors do not simply equalize their investment across trustees under both information conditions, but, consistent with our hypotheses, there is a greater variety of investment levels within a portfolio under the private information condition.

6.3. Discussion

Experiment 1 lends support to all our Investor hypotheses. Consistent with Investor hypothesis 2, total invested amount increases when information flow between trustees is restricted. Also in line with Investor hypotheses 1 and 3, there is a greater variety of investment levels within a portfolio when information flow is restricted. We moreover observe, as predicted by Investor hypothesis 2, that the number of trustees receiving positive investment does not change across information conditions; the increase in total investment is predominantly driven by an increase in average investment among trustees who receive positive investment.

7. Experiment 2: trustee behavior

Experiment 2 was designed to test trustees’ behavior—in particular to try to isolate evidence of reactions to unfairness and moral obligation free riding.

7.1. Methods

7.1.1. Subjects

Seventy-eight undergraduate subjects at the Hong Kong University of Science and Technology, 29 in the role of investors and 58 in the role of trustees, participated in the experiment. All subjects volunteered to take part in a decision making experiment with payoff contingent on performance.

7.1.2. Procedure

Subjects were randomly assigned to be investors or trustees such that each investor was matched randomly and anonymously with two trustees. As in Experiment 1, the investor had an endowment of $50 in each played game, while the trustees had no endowment. Any investment by the investor was tripled when it reached the trustee. Both investors and trustees were presented with a menu of seven investment patterns for the \( N=1 \) game and 16 investment patterns for the \( N=2 \) game. The patterns, as shown in Table 4, exhaust all possible investment portfolios in either game in which any investment on any trustee is restricted to the amounts \( 0, 10, 20, 25, 30, 40, \) and \$50. All \( N=2 \) games were played under the public information condition. Each investor was asked to choose one pattern from the \( N=1 \) game and one pattern from the \( N=2 \) game as her investment portfolios for the two games. We used the strategy method for the trustees; before being informed of the investor’s decision, each trustee was asked to decide, for each investment pattern, how much to reciprocate (if at all) if she received the underlined amount (see Table 4). The patterns were presented one at a time in randomized order to the trustees.

9 The hypothesis is satisfied trivially for \( N=2 \).
Table 4
The menu of investment patterns; all amounts are in $ (Experiment 2).

<table>
<thead>
<tr>
<th>N = 1</th>
<th>N = 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At most one trustee receives positive investment</td>
</tr>
<tr>
<td>0</td>
<td>(10)</td>
</tr>
<tr>
<td>20</td>
<td>(40)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unequal positive investments</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,20</td>
</tr>
<tr>
<td>10,40</td>
</tr>
<tr>
<td>20,10</td>
</tr>
<tr>
<td>20,40</td>
</tr>
<tr>
<td>20,25</td>
</tr>
<tr>
<td>10,30</td>
</tr>
<tr>
<td>20,30</td>
</tr>
<tr>
<td>25,10</td>
</tr>
<tr>
<td>30,10</td>
</tr>
<tr>
<td>30,20</td>
</tr>
</tbody>
</table>

Subjects were paid the average of the payoffs they received in the two games. In addition, each subject was paid a show-up fee of $10. Not including the show-up fees, average investor payoff was $43.16 and average trustee payoff was $25.66.

7.2. Results

7.2.1. Trustee’s reciprocated amount

Trustees’ stated reciprocated amounts in response to different investment patterns constitute our major dependent variable. The data are presented in Table 5. For example, the figure in the cell (10, N = 1) in Table 5 denotes the mean reciprocated amount in response to being sent $10 by the investor in an N = 1 game; the figure in the cell (25, 20) denotes the mean reciprocated amount in response to being sent $25 by the investor in an N = 2 game while also knowing that the other trustee was sent $20.

Note that the standard deviations are large compared with the means; individual differences are expectedly large with this kind of task, and with each trustee making so many decisions under the knowledge that only two of the decisions would affect her real payoff, it is inevitable that the data are quite noisy. However, we do find evidence in support of our trustee hypotheses.

As in previous studies, trustees do reciprocate positively. In fact, Sign tests show that all amounts are significantly greater than zero at p < .0001 level. Next, we examine whether the data reveal any concern for fairness as summarized in Trustee hypothesis 1. If that hypothesis is true, we should observe that trustees reciprocate no more in $x, N = 1$ than in $x, N = 2$ (using the notation of investment patterns in Table 4 to denote decision making condition), controlling for $y$. This corresponds to comparing the first and second column of figures in Table 5 in $x = 10, 20, 25, 30, 40, 50) \times 2(x) \times 2(y)$ design. Consistent with the hypothesis, there is no main effect along the dimension $x$ vs $x, N = 1$ (with $p = .32$. Overall, being treated favorably in the N = 2 game, while keeping the total investment fixed as in the N = 1 game, does not result in a higher propensity to reciprocate due to gratefulness. If at all, a closer inspection of the data pattern suggests that a net undermining of reciprocating propensity due to unequal allocation is present at high levels of $x$. We test the statistical validity of this observation through one-tailed within-subject ANOVA; indeed, reciprocated amounts are significantly lower in the $x, N = 1$ condition compared with the $x, N = 2$ condition at the $x = 30, 40$ and 50 levels ($F(1, 57) = 3.04, p < .05$). Meanwhile, no difference in reciprocated amounts at the $x = 10, 20$ and 25 levels is detected ($p > .1$). To sum up, our data lend support to Trustee hypothesis 1. Further, there is, for high levels of received investment, positive evidence of trustees reciprocating less when faced with unfair distribution of investment, even when they are on the preferential side of the allocation. It seems that trustees are especially sensitive to the unfairness of the distribution (even though they are on the advantageous end of the inequality) when the unfairness is pronounced, but not so when it is not so explicit.

Lastly, we look for signs of moral obligation free riding. Trustee hypothesis 2 suggests that, controlling for $x$, trustees reciprocate no more in $(x, y)$ than in $(x, 0)$ when $y$ is positive but sufficiently smaller than $x$. Consequently, we will focus on conditions under which $x$ is at least three times of $y$ (i.e., $x = 30$ and $40$ with $y = 10$). We look for a main effect in the design $(x = 30, 40) \times \{x, 0\} \times \{x, 10\}$ along the dimension $(x, 0) \times (x, 10)$. Directionally, the data pattern is indeed consistent with

Table 5
Average (S.D.) reciprocated amounts in $ by trustees (Experiment 2).

<table>
<thead>
<tr>
<th>Investment received ($)</th>
<th>N = 1</th>
<th>N = 2</th>
<th>N = 2: investment received by the other trustee ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.45 (6.59)</td>
<td>4.45 (7.32)</td>
<td>3.66 (5.82)</td>
</tr>
<tr>
<td>10</td>
<td>10.17 (10.60)</td>
<td>10.41 (12.13)</td>
<td>12.83 (13.11)</td>
</tr>
<tr>
<td>20</td>
<td>15.19 (13.76)</td>
<td>15.29 (15.93)</td>
<td>15.53 (14.98)</td>
</tr>
<tr>
<td>25</td>
<td>21.62 (18.67)</td>
<td>19.78 (18.99)</td>
<td>18.71 (18.29)</td>
</tr>
<tr>
<td>30</td>
<td>29.29 (23.52)</td>
<td>28.97 (25.76)</td>
<td>28.34 (25.44)</td>
</tr>
<tr>
<td>40</td>
<td>40.16 (31.94)</td>
<td>35.95 (33.50)</td>
<td></td>
</tr>
</tbody>
</table>
the hypothesis; however, the effect is not significant, with $p > .1$. We suspect that this is because $y = 10$ is not sufficiently small relative to the levels of $x$ in our test to reveal a dominant effect of moral obligation free riding. However, there is indeed directional evidence in support of Trustee hypothesis 2 and the underlying premise that opportunity in moral obligation free riding undermines trustees' propensity to reciprocate.

7.2.2. Investors’ choices of investment

The investors’ choices of investment patterns are summarized in Table 6. Eleven investors choose the subgame perfect equilibrium strategies of zero investment for both games; in addition to these investors, one investor chooses the zero-investment strategy for the $N = 1$ game but not the $N = 2$ game, while another chooses this strategy for the $N = 2$ but not the $N = 1$ game.

<table>
<thead>
<tr>
<th>Investment received by one trustee ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N = 1$</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

$N = 2$: investment received by the other trustee ($) |

| 10 | 20 | 25 | 0 |

Experiment 2 offers support to our conjectures regarding trustee behavior. Fundamentally, it shows that, under the public information condition, a trustee’s reciprocating behavior is dependent not only on her received amount but also on other trustees’ received amounts. The data are also largely consistent with Trustee hypotheses 1 and 2, which are respectively about trustees’ reactions to a non-uniform investment distribution and moral obligation free riding. Investor choices in this experiment reveal less inclination to trust than in Experiment 1, but it must be noted that the natures and formulation of the tasks are quite different in the two experiments. Total investment, meanwhile, increases with $N$, which agrees with the results in Experiment 1.

7.3. Discussion

Experiment 2 offers support to our conjectures regarding trustee behavior. Fundamentally, it shows that, under the public information condition, a trustee’s reciprocating behavior is dependent not only on her received amount but also on other trustees’ received amounts. The data are also largely consistent with Trustee hypotheses 1 and 2, which are respectively about trustees’ reactions to a non-uniform investment distribution and moral obligation free riding. Investor choices in this experiment reveal less inclination to trust than in Experiment 1, but it must be noted that the natures and formulation of the tasks are quite different in the two experiments. Total investment, meanwhile, increases with $N$, which agrees with the results in Experiment 1.

8. General discussion and areas for future research

Our experimental results are consistent with the hypotheses proposed in this paper. They suggest that people (or possibly firms), when faced with the problem of investing in trust–reciprocity relationships with more than one social contact, business partner or customer under resource constraints, would neither play the subgame perfect equilibrium strategy of giving out nothing nor send out a great variety of different amounts of investment. They may not equalize their investments across everyone either. More importantly, whether the trustees can communicate with each other regarding how much they have received from the investor has a significant influence on the amount of trust–dependent transactions; in fact, Experiment 1 supports the proposition that a trust–reciprocity relationship is more easily built under restricted information flow compared with under the public information condition. In terms of “welfare of the society”, which is simply dependent on total investment, restricting information flow definitely has an advantage. Experiment 2 suggests that factors that are extraneous to a trustee’s own received investment, such as inequality in investment distribution or whether there is an opportunity to free ride on other trustees’ moral obligations to reciprocate, affect the reciprocated amount.

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10 We have not included conditions with lower values of $y$ in our design because of the need to keep the number of investment patterns small enough to maintain subject attention to each pattern at a reasonable level, while also making the patterns as symmetric and representative as possible of the “real” $N = 2$ game.
The finding that restricting information flow enhances trust-dependent transactions indeed corresponds to the fact that many transactions in reality that involve large sums and trusting cooperation (from infrastructure building contracts to commercial film deals with stars and directors) are made with limited transparency to outside parties. The trust-reciprocity concerns discussed and experimentally investigated in this paper provide some insight into why this “confidentially yours” approach is so widespread, at least in the case when one contracting party is simultaneously making deals with many other parties. If information about the deals becomes fully transparent, the “investor” party has to consider the possibility that the other parties would call for “fair dealings”, or they might work less hard for the contract if they knew that other parties have also been given good deals—a behavioral concern that adds to the traditional moral hazard problem.

Evidence from Experiment 2 supports the idea that a trustee’s propensity to reciprocate under the public information condition can be undermined in the face of unfair distribution of investment, including when the trustee is receiving much more than what others receive; this therefore presents an instance when being treated preferentially does not necessarily lead to higher reciprocating “effort” in return. While distributional fairness is a widely researched topic in the literature (e.g. Güth et al., 1982; Bazarman et al., 1995), focus has been mainly on the behavior of subjects who are treated “less than” fairly rather than “more than” so, which is studied here.

In the long run, a natural complement to the present investigation is to consider the case when N>1 investors may send money to one trustee. In fact, combining N>1 investors and N>1 trustees, and allowing each subject to be both investor and trustee in a repeated game, will yield a network of mutual trust and reciprocity (in which each player can freely choose who to send money to) that is complex and potentially rich in dynamics. We predict that trust-reciprocity relationships within certain subgroups or pairs of players will emerge in the repeated game in such networks, resulting in long-term mutual gift giving. Van der Heijden et al.’s (2001) two-person repeated gift-exchange game lends some support to a strong form of our prediction. In their arrangement, the highest payoff for both parties can be achieved only in a complex exchange scenario where players take turns donating large gifts and no gift; not only trust and reciprocity but also well-tuned cooperation needs be established for complex exchanges to take place seamlessly. Without direct communication, this is presumably difficult to achieve. However, van der Heijden et al. observe that some players (but not all) were able to sustain long periods of complex exchanges after overcoming coordination problems in the early rounds. If this can occur in a two-person game, it may also occur in an N-person game, though probably only in certain subgroups or pairs in which not only trust and reciprocity but also a high degree of cooperation has been established that maximizes the subgroup members’ payoffs.

In fact, from this perspective, the present research can be seen as an initial step in an experimental investigation into an aspect of network formation and dynamics, a topic that has been attracting interest in recent decades (e.g. Bala and Goyal, 2000; Goeree et al., 2005; Jackson and Wolinsky, 1996; Wasserman and Faust, 1994). As Ostrom (2002) notes, in social situations in which trust and cooperation within a large population are difficult to establish at once, subgroups may be formed first. It will be of value to demonstrate subgroup formation in a network investment game in which trust and cooperation within the whole group are indeed difficult to achieve.

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References