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Investing to cooperate: theory and experiment.*†

Jean-Pierre Benoit‡ Roberto Galbiati§ and Emeric Henry¶

Abstract

We study theoretically and in a lab-experiment investment decisions in environments where property rights are absent. In our setting a player chooses an investment level before interacting repeatedly with a given set of agents. The investment stochastically affects the payoffs of the game in every subsequent period. We show that investments with less volatile returns are more likely to be observed since they facilitate cooperation. We also show that the investor might be forced to invest more than he would in an environment with legal protection, to keep other players cooperative. Experimental results are broadly consistent with the theoretical findings.

JEL: C72, C73, C91, C92

KEYWORDS: investment, experiments, repeated games, property rights

1 Introduction

An entrepreneur considers investing in a foreign country where there is a risk of expropriation. A user of a public good needs to invest to improve its quality in a setting where overuse of the public good is a serious concern. A firm must decide how much to invest in innovation in an environment where intellectual property rights are weak. In these types of situations with weak property rights, how do the characteristics of the environment affect investment?

It is well understood that repeated interactions can serve as a substitute for legal enforcement. In this paper, we examine how informal enforcement, through repeated interactions,

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affects the initial investment decision. First, we find that, the characteristics of the environment affect investment differently when legal protection is present than when it is absent. In particular, controlling for mean returns, investment is more likely when returns are less volatile, even if agents are risk-neutral. Second, we show that the absence of protection may sometimes foster greater investment and we characterize conditions, based on the shape of returns or characteristics of the game, that lead to these high levels of investment.

We conduct a laboratory experiment and, to some extent, the theoretical framework is built to structure and guide the interpretation of the experiment. Our experiment is designed to understand investment decisions in environments where property rights are absent and this can become a promising avenue of research for providing evidence on an issue extremely difficult to test with field data.¹ The experimental results are broadly consistent with our theoretical findings. Furthermore, the experiment contributes to the growing literature on infinitely repeated games in the lab. Finally, it also has value in shedding light on equilibrium selection in a setting characterized by multiple equilibria.

The basic structure of our theoretical model is as follows. An agent, Player 1, makes an initial investment which determines the i.i.d. stochastic distribution of payoffs in subsequent periods. In the absence of property rights, there are N other players who can grab a share of the payoffs in any period. We model the interaction of the $N + 1$ players as an infinitely repeated prisoner's dilemma. We know theoretically that repeated interactions can serve as a substitute for outside enforcement. If players are arbitrarily patient, it is easy to sustain investment even without legal protection.

With players who are only moderately patient, investment is more difficult. We show that the shape of the distribution of returns, in particular its volatility, determines what investments can be observed in equilibrium. Specifically, if an investment level k is part of an equilibrium for a distribution of returns F , it will also be for a different distribution that second order stochastically dominates F .

The intuition is the following. In the absence of legal protection, investment may require that players be able to cooperate, so that Player 1 can recoup his initial outlay. This "cooperation condition" is more easily satisfied when returns from investment are less volatile. To see this, consider two distributions with identical mean but where the first is more volatile and payoffs can take larger values. In a period where a large payoff is obtained, the temptation to deviate and grab a greater share of the payoff is acute, while the promise of the future remains fixed. It thus becomes less likely that the players are able to cooperate along

¹A similar argument in favour of experiments in economics is given in Falk and Heckman (2009), where the authors focus in particular on the application to employment relations. Meloso et al. (2009) also conduct an experiment capturing innovative behavior where they compare different reward mechanisms.

paths that sometimes have very large period payoffs. This observation implies that, holding expected returns fixed, we should see relatively more low variance investments when legal protections are weak.

We then compare the results to a benchmark model with legal protections that ensure that the agent captures the rents from his investment. We show that there are circumstances under which an agent will invest more if the investment is not legally protected. The reason is that higher initial investments shift up the distribution of future returns, thereby facilitating cooperation as the future returns to cooperation increase.²

The experimental framework echoes the theoretical setup. Participants are randomly matched in pairs and one member of each pair initially has to make an investment, among five choices. This initial investment determines, in each period of the indefinitely repeated game that follows, the probability of getting a prize of fixed value. In treatments without protection, the two participants play a prisoner's dilemma. We run two types of treatments where we vary the investment options, keeping the expected return fixed. For a given investment, in one treatment there is a high probability of having a low positive return and in the second a low probability of obtaining a high positive return (with the same mean). The payoffs are such that any investment level is an equilibrium in the first type of treatment, while an intermediate level of investment is not an equilibrium in the second, where returns are more volatile.

We find, in coherence with the logic sketched above, that cooperation is observed less often in the second treatment following an out of equilibrium behavior. Furthermore, in the second treatment, both the zero investment outcome and strictly higher levels of investments become more likely, suggesting that participants are indeed more likely not to invest the level which is no longer an equilibrium. Moreover, some participants revert to the degenerate equilibrium – no investment/ no cooperation – while others choose to invest more to foster cooperation. We also run treatments with legal protection where the investor obtains the full prize following the investment. We find that the average level of investment in treatments with and without protection are comparable.

Our study contributes to the recent experimental literature on cooperation and collusion in infinitely repeated games (Dal Bo 2005; Dreber et al. 2008; Camera and Casari 2009; Aoyagi and Frechette 2009; Dal Bo and Frechette 2011; Bigoni, Potters and Spagnolo 2012). As in several of these papers, our findings highlight the fact that players are sensitive to the future expected profits when taking their current decisions.³ However, while this literature

²Note that we make no claim that these higher levels of investment are welfare increasing. Among other things, in the presence of high fixed costs welfare comparisons depend upon how much of the surplus firms manage to capture.

³Indeed we will find that cooperation is higher when the investor invested more initially.

has mainly focused on understanding both the dynamics of cooperation and the conditions favouring collusion or cooperation in infinitely repeated games, our focus is on the comparison of investment choices under different institutional regimes. To the best of our knowledge, we are the first to examine experimentally this type of game where a date zero decision influences the type of game played repeatedly afterwards. Furthermore, this paper is also one of the few that offers an experimental comparison of environments with and without protection.

The idea that repeated interactions can serve as a substitute for legal enforcement is already well developed. Greif (1989, 1993) provides historical evidence. It is also the starting point of the relational contracting literature (Klein and Leffler 1981, Levin 2003) that looks more in detail at the contractual terms when interactions are repeated and contracts incomplete. However, in these papers, investment is absent. One exception is Halac (2013), who examines a similar setup to ours, with an investment decision before a repeated game. She also finds that investment might be higher than in a fully contractible benchmark. Whereas our player invests more in order to facilitate cooperation in a prisoner's dilemma, in Halac the player invests more in order to increase her payoff from a bargaining game. The focus of Halac's paper is quite different than ours and this is reflected in the setup of her model. Halac is interested in studying the contractual terms, not the conditions that favor investment in the absence of protection nor comparing investment levels across protection regimes. In particular, the returns in her model (provided agents trade) are identical across periods and she therefore cannot obtain results in the spirit of our second order stochastic dominance argument. In addition, since an important contribution of our paper is the experimental evidence, our theoretical model is partly targeted towards formulating lab-testable implications.

Ramey and Watson (1997) also examine a setting where a prior investment affects the shape of a prisoner's dilemma (in their setting, the investment affects only the payoff when both cooperate). They share the idea that higher up-front investment favors cooperation. They do not, however, focus on the comparison of investment levels between regimes nor do they study the types of investment we can expect across regimes. They focus more specifically on how this initial decision endogenously affects job destructions over the business cycle. In a very different setup, Levine and Modica (2013) also examine a prior investment stage before a repeated interaction. The game is a public goods game and they focus on how peer discipline can encourage initial investment.

Our paper is also related to the literature on collusion in Rotemberg and Saloner (1986), who study collusion in a stochastic environment over the business cycle. We add investments in this framework. One interpretation of our model is that it endogenizes the shape of

the business cycle. We also model the stochastic return differently, which allows us to characterize the condition on second order stochastic dominance. In a similar vein, Dal Bo (2007) studies collusion when the interest rate fluctuates.

Our theoretical and experimental results can speak to the renewed debate on the use of patents to encourage investments in innovation (Boldrin and Levine 2008, Bessen and Hunt 2007).⁴ Our results show that legal protection is not necessary for positive levels of investment, and that the absence of patents may even lead to more innovation. There is some empirical evidence consistent with this idea. We describe in the conclusion the case of Red Hat, a very successful company selling an open source operating system and investing heavily in research. As acknowledged in Red Hat’s annual report: “anyone can copy, modify and redistribute Red Hat Enterprise Linux”. Numerous clones do indeed exist, but they appear to avoid competing aggressively and do not gain much market share. We argue this behavior is coherent with our theory and that Red Hat could potentially be more innovative than if it had full property rights on its innovations.

The remainder of the paper is organized as follows. In Section 2, we introduce the model. In Section 3, we characterize the equilibria and derive our main theoretical results. In Section 4, we present the experimental setup and results. All proofs, tables and figures are presented in the appendix.

2 Model

In this section, we present a formal model that is general enough to encompass many scenarios of interest. In the next section, we supply several applications.

In period 0, Player 1 makes an initial investment k . The size of this initial investment stochastically affects the payoffs in subsequent period. Specifically, given a period 0 investment k , $F(\pi, k)$ is the i.i.d. cumulative probability distribution of the payoff relevant variable $\pi \geq 0$ in each subsequent period. We assume that $F(0, 0) = 1$, so that investment is necessary for a positive return, and, for $k' > k$, $F(\pi, k')$ (weakly) first order stochastically dominates $F(\pi, k)$.

In the game with legal protection, that we use as a benchmark, in period $t \geq 1$ player 1 mechanically collects the payoff realization π_t while the other players earn 0. Player 1

⁴Boldrin and Levine (2008) and Bessen and Hunt (2007) suggest that the software industry was more innovative before the introduction of patents. Our theory suggest one channel. There are a number of papers explaining how innovation may occur in the absence of any kind of formal protection (Scherer and Ross 1990, Benoît 1985, Henry and Ponce 2011, Henry and Ruiz-Aliseda 2012, Boldrin and Levine 2002 and 2005, see also Anton and Yao 1994 and 2002). These papers show, in different environments, that innovation can occur in the absence of formal protection. However, in all these contributions, less innovation is conducted than if the innovator was granted a monopoly.

chooses an investment level that maximizes his total expected discounted profits. That is, Player 1 chooses k (in period 0) to maximize $-k + \sum_{t=1}^{\infty} \delta^t \int_0^{\infty} \pi dF(\pi, k) = -k + \frac{\delta}{1-\delta} E(\pi|k)$, where $E(\pi|k) = \int_0^{\infty} \pi dF(\pi, k) < \infty$. We suppose the maximization problem has a solution $k^* > 0$.

Without legal protection, following Player 1's initial investment the $N + 1$ players engage in an infinite horizon game, as follows. In each period $t \geq 1$, the players play a prisoner's dilemma whose "scale" depends on the realization π_t . As we will see, it is more difficult for firms to cooperate in a period where the payoff realization is large. Hence, it may be in Player 1's interest to restrict the size of the payoff and we give him the option of doing so by choosing, at no cost, a maximum value $\bar{\pi}$ that the variable π can take. We allow that $\bar{\pi}$ can be chosen to be ∞ , so that no constraint is imposed.

More precisely, the players engage in the following game:

- In period $t = 0$, Player 1 chooses $k \geq 0$ and $\bar{\pi} \in (R_+, \infty)$.
- In each period $t \geq 1$,
 1. A draw π_t of the payoff relevant variable is taken from $F(\pi, k)$.
 2. Every player chooses between two actions C ("cooperate") and D ("deviate") as a function of (h_t, π_t) , where h_t denotes the history of play up to date t .
- With two players, i.e., $N + 1 = 2$, payoffs are described by the following matrix, where $\hat{\pi}_t = \min(\pi_t, \bar{\pi})$:

	C	D
C	$(\alpha_1 \hat{\pi}_t, \alpha_o \hat{\pi}_t)$	$(\gamma_1 \hat{\pi}_t, \beta_o \hat{\pi}_t)$
D	$(\beta_1 \hat{\pi}_t, \gamma_o \hat{\pi}_t)$	$(\lambda_1 \hat{\pi}_t, \lambda_o \hat{\pi}_t)$

We assume $\beta_i > \alpha_i$, $\lambda_i \geq \gamma_i$, $\lambda_i < \alpha_i$, and $1 > \beta_i$. These conditions mean that the game played in each period is a prisoner's dilemma, albeit one with, potentially, weakly dominant strategies rather than strictly dominant ones. This potential difference is not important and is only relevant for the experiment we run. The condition $\beta_1 < 1$ ensures that Player 1 always does worse in the absence of legal protections.

- The game with $N + 1$ players generalizes the matrix. If everyone plays C , the payoff of player 1 is given by $\alpha_1 \hat{\pi}_t$ and the payoff of players $\{2, \dots, N+1\}$ is given by $\alpha_o \hat{\pi}_t$. If player 1 plays D and all the others play C , player 1 obtains $\beta_1 \hat{\pi}_t$ and players $\{2, \dots, N + 1\}$ obtain $\gamma_o \hat{\pi}_t$. If a single player other than 1 deviates, player 1 gets $\gamma_1 \hat{\pi}_t$, the deviator gets $\beta_o \hat{\pi}_t$ and all the others get $\gamma_o \hat{\pi}_t$. Finally, if at least two players play D , player 1 obtains

$\lambda_1 \hat{\pi}_t$ and the other players obtain $\lambda_o \hat{\pi}_t$.⁵ Again, $1 > \beta_i > \alpha_i > \lambda_i \geq \gamma_i$. Throughout, we consider games where the payoff of players $\{2, \dots, N + 1\}$ are symmetric, though our results can be extended to allow for asymmetries.

The dynamic game will typically have many equilibria. For ease of exposition, we restrict ourselves to *symmetric subgame perfect equilibria*. In such equilibria, along the equilibrium path of play, either every player chooses C or every player chooses D . Our analysis can be extended to allow for asymmetric equilibria. In Section 3.2, we discuss an example in which we consider all equilibria, without affecting the results. We note also that the restriction to symmetric strategies is less severe than it may at first appear as the stage game itself may be asymmetric. Thus, when the players cooperate this could be with a split that purposely favours Player 1 – that is, $\alpha_1 > \alpha_0$ – in order to compensate Player 1 for his initial investment.⁶

For player i , $\alpha_i - \lambda_i$ provides a measure of the gains from cooperating, while $\beta_i - \alpha_i$ measures the instantaneous benefits from deviating. It turns out that an essential characteristic of the game is the following parameter, which we call the “cooperation ratio” of the game:

$$R \equiv \min_i \left[\frac{\alpha_i - \lambda_i}{\beta_i - \alpha_i} \right]$$

The cooperation ratio will be shown to be useful in structuring comparisons between investment levels with and without protection. Below, we study some applications of the model.

2.1 Application 1: investing in countries with weak property rights

Institutions play a key role in the amount of foreign direct investment flowing into countries (Benassy-Quere et al 2007; Wheeler and Mody 1992; Daude and Stein 2007). The enforcement of legal rules also impacts the type of sectors attracting investments, although evidence is a bit scarce. Our model can capture the decision of a firm investing in a country where it faces a risk of expropriation. The size of the initial investment affects the stochastic

⁵These payoffs are chosen to keep the notation to a minimum. In most applications of the model, it makes more sense for a player’s payoff from choosing D to strictly decrease as the number of other players choosing D increases. We could make that assumption instead without changing our results.

⁶In a more general model, the shares of the players could be made endogenous. We have analyzed such a model for the special application of innovation. There, the players play a pricing game in which they may generate an uneven split by choosing different capacities. (Giving Player 1 a greater share eases his investment constraint but makes cooperation more difficult in the subgame.) With appropriate modifications, the results of this paper go through.

production that the investment can generate. In each period that follows, the government decides whether or not to expropriate the firm.

Specifically, we think of expropriation as imposing a very high tax rate. The firm decides whether to evade taxes and the government simultaneously decides on the tax rate. In the case of a reliable legal system, the tax authority cannot arbitrarily impose an exorbitant high tax rate and the firm cannot evade. In the absence of a reliable legal system, the two players play a prisoner's dilemma. For the firm, C corresponds to not evading and paying the full amount of taxes while D corresponds to evading a fixed portion $1 - e$ of the production at a cost $c(1 - e)\pi$ (cost of dissimulating some income). For the tax authority C corresponds to picking a low tax rate $\underline{\tau}$ and D a high one $\bar{\tau}$ (i.e., expropriate the firm). The game is then the following:⁷

	C	D
C	$((1 - \underline{\tau})\pi, \underline{\tau}\pi)$	$((1 - \bar{\tau})\pi, \bar{\tau}\pi)$
D	$((1 - \underline{\tau})e\pi + (1 - c)(1 - e)\pi, \underline{\tau}e\pi)$	$((1 - \bar{\tau})e\pi + (1 - c)(1 - e)\pi, \bar{\tau}e\pi)$

We return to this example at the end of section 3.2 when interpreting the results.

2.2 Free-rider problem with weak property rights

In her Nobel lecture (2010), Ostrom describes her work on the different institutional arrangements governing common pool resources. Referring to large scale studies of irrigation, she notes that “farmer-managed systems are likely to grow more rice, distribute water more equitably and keep their systems in better repair than government systems.” In the case of forests, she describes activities undertaken by some members of the community to preserve the quality of the public good.

Our model can be used to describe the interaction between users of a public good (such as the wood from a forest in Ostrom's example). In period 0, Player 1 has the capacity to make an initial investment that will increase the quality of the public good. In each period t , a draw of π_t is taken, where π_t is total size of the public good. The stochastic aspect in the case of the forest is due, say, to fluctuating weather conditions.

With legal property rights, Player 1 controls access to the good. Without property rights, following a realization π_t the players decide on their levels of consumption of the public good. Action C corresponds to consuming a low amount and D a high amount. Consumption at the low level provides a personal benefit, while exerting minimal externalities on the other

⁷To satisfy the constraints imposed on the coefficients, we need the following conditions $(1 - \underline{\tau})\pi < (1 - \underline{\tau})e\pi + (1 - c)(1 - e)\pi$, $\underline{\tau}\pi < \bar{\tau}\pi$, $(1 - \underline{\tau})\pi > (1 - \bar{\tau})e\pi + (1 - c)(1 - e)\pi$ and $\underline{\tau}\pi > \bar{\tau}e\pi$. Sufficient conditions are $\underline{\tau} > c$ and $\bar{\tau}e - \underline{\tau} + c(1 - e) > 0$.

parties. Consumption at a high level imposes significant costs, so that all players consuming at a high level is unsustainable for that period. As written, this model does not take into account the dynamics of overuse of the public good in the sense that there is no linkage between the consumption today and the level of π tomorrow. The externality is captured here only within the period, but the model could be generalized to capture the dynamic externality.

2.3 Application 3: investment in innovation

A growing share of innovation is conducted without the protection of patents. Consider the case of the firm Red Hat, which we discuss in more detail in the conclusion. Most of its revenues come from the sale of a pre-compiled version of the open source operating system Linux, called Red Hat Enterprise Linux. Anyone can copy and resell this software and numerous clones do indeed exist. However, these clones tend not to be very aggressive. Furthermore, even in this environment with no protection, Red Hat invests a lot in innovation: it is the biggest contributor to the Linux Kernel and pays the salaries of most of its researchers.

The model can be used to represent the interaction between an innovator and a set of imitators, such as Red Hat and its clones. With this interpretation, the initial investment k is an investment in innovative capability, such as a research facility. This investment determines the probability distribution of future innovations.⁸ In each period, the firm randomly develops an innovation which can instantly be brought to market. The market value of an innovation degrades over time; for simplicity, the life span of a new product is exactly one period. The realization $\pi_t \geq 0$ is then monopoly profits in period t . In each period, the firms play a prisoner's dilemma in which defecting corresponds to charging a low price, while cooperating corresponds to charging the monopoly price, with one caveat: if the payoff realization is exceptionally high, the firms may choose to cooperate on a lower price yielding $\bar{\pi}$ instead of π . This possibility is modeled by firm 1's choosing $\bar{\pi}$ in period 0.

With this interpretation, an innovator with a patent simply captures monopoly profits. Without a patent, suppose that marginal cost is constant and, say, the firms split the market symmetrically when they cooperate. We then have $\alpha_i = \frac{1}{N+1}$, $\frac{1}{N+1} < \beta_i < 1$, $\gamma_i = 0$, and $0 \leq \lambda_i < \frac{1}{N+1}$.⁹ By setting $\lambda_i = 0$, we can think of (D, D) as a reduced form way of modeling

⁸In a more general model, this stock investment would be complemented by on-going research expenditures. We considered such a model in an earlier version, but this complication does not change our main results.

⁹Thus, if $N = 4$, when two firms play D each one earns $\frac{c}{5}$, which is the same payoff they would earn if all the firms played D . As indicated in footnote 4, this is for notational ease. We could instead have that when m firms play D each one earns $\frac{c}{m}$ without affecting our results.

a price war down to marginal cost.

3 Investing to cooperate

3.1 Equilibria

In the absence of legal protection, there always exists a *degenerate* equilibrium in which everyone plays D in periods $t = 1, 2, \dots$, regardless of the value of π , and Player 1 invests, accordingly, $k_d = \arg \max_k \left\{ -k + \frac{\delta}{1-\delta} \lambda_1 \int_0^\infty \pi dF(\pi, k) \right\}$. If returns are small when players do not cooperate (i.e., λ_1 small), then k_d will be small and may well be zero. This is the outcome most people have in mind when thinking of environments without legal rules.

There can also exist non-degenerate equilibria where Player 1 invests a significant amount. Indeed, it is already well understood that repeated interactions can serve as a substitute for legal enforcement. For any investment k , if players are arbitrarily patient they will be able to cooperate in the subgame following period 0. Moreover, the discounted sum of payoffs from repeated cooperation will more than compensate an arbitrarily patient Player 1 for his investment.

However, while significant investment may be easy with arbitrarily patient players, it is trickier with moderately patient players who value short term gains. Proposition 1 describes the conditions for an investment of $k \neq k_d$ by Player 1 to form part of an equilibrium. These conditions are that *i*) the players manage to play cooperatively – hence, they prefer playing C in every period to deviating for one period and subsequently obtaining the non-cooperative payoff forever (which is captured by condition (2) below) and *ii*) Player 1 prefers investing k to playing the degenerate equilibrium (condition 3).

Proposition 1 *A choice of k by Player 1 forms part of a symmetric subgame perfect equilibrium if and only if either, a)*

$$k = k_d \tag{1}$$

or b) there exists a $\tilde{\pi}$ such that:

$$\tilde{\pi} \leq \frac{\delta}{1-\delta} R \left(\int_0^{\tilde{\pi}} \pi dF(\pi, k) + \tilde{\pi} (1 - F(\tilde{\pi})) \right) \tag{2}$$

and

$$-k + \frac{\delta}{1-\delta} \alpha_1 \left(\int_0^{\tilde{\pi}} \pi dF(\pi, k) + \tilde{\pi} (1 - F(\tilde{\pi})) \right) \geq -k_d + \frac{\delta}{1-\delta} \lambda_1 \int_0^\infty \pi dF(\pi, k_d) \tag{3}$$

Consider a path where Player 1 has limited the maximum payoff realization to $\tilde{\pi}$ by choosing $\bar{\pi} = \tilde{\pi}$ in period 0. Condition (2) guarantees that the players cooperate for all payoff realizations smaller or equal to $\tilde{\pi}$ (if there are no incentives to deviate for a realization $\tilde{\pi}$, then it is also the case for a realization $\pi \leq \tilde{\pi}$). The term $\int_0^{\tilde{\pi}} \pi dF(\pi, k) + \tilde{\pi}(1 - F(\tilde{\pi}))$ is the expected per period payoff when, for any realization of π above $\tilde{\pi}$, the payoff is limited to $\tilde{\pi}$.

To understand the reason that Player 1 may choose to impose an upper bound $\bar{\pi}$, let $\tilde{\pi}_{\max} = \{\sup \tilde{\pi} \text{ s.t. (2) holds}\}$. Since the right hand side of (2) is bounded (by $\frac{\delta}{1-\delta} R * E(\pi|k)$), we have $\tilde{\pi}_{\max} < \infty$. The quantity $\tilde{\pi}_{\max}$ provides an upper bound on the realization of π for which players can cooperate when player 1 invests k . Thus, it is in Player 1's interest to limit the returns to the investment to be at most $\tilde{\pi}_{\max}$ and to choose $\bar{\pi} = \tilde{\pi}_{\max}$ in period 0. If not, for realizations $\pi > \tilde{\pi}_{\max}$, players would be unable to cooperate, low returns would be obtained, and the overall expected return would be lowered.

At a more intuitive level, the higher the draw of π , the larger the temptation to deviate and play D , since the immediate gains from deviating are increasing in π while the future expected draws and potential gains to cooperating are unaffected (draws are i.i.d). Suppose that π takes only two values π_L and π_H and that when π takes the value π_H , players are unable to cooperate, while it is possible for a value π_L . It would then be in the interest of the players, when the draw of π is π_H , to restrict the value of π to be π_L , to allow for cooperation. For instance, under the innovation interpretation from Section 2.3, the players engage in a pricing game following a successful innovation. If the firms are not able to share monopoly profits when the draw is very high, they might still find a lower price where cooperation is possible.¹⁰

The existence of the upperbound $\tilde{\pi}_{\max}$ on the cooperative period payoff suggests that the total surplus may be lower in the world without legal enforcement. This fact, combined with the fact that Player 1 must share the returns from investment, and the need to satisfy equilibrium constraints, implies that there may be some investment levels that, while profitable with legal protection, do not form part of an equilibrium without such protection. Somewhat counter-intuitively, we show that this may lead to higher equilibrium investments in the absence of legal protections, to relax the investment constraint 2.

The conditions in Proposition 1 highlight the key role of the distribution F . We explore in section 3.2 the role of the volatility of returns. We then explore in section section 3.3 how

¹⁰The equilibria found by Rotemberg and Saloner (1986) have a similar feature, and our framework, interpreted as in application 1, is similar to the one they use in their study of collusion in the face of uncertain demand. We add the essential element of initial investment and use a simpler and more general setup. Note also that we use a shock on monopoly profits rather than a shock on demand used in their framework. This difference is crucial for the comparative statics we perform in Section 3.2.

legal rules affects the level of investment.

3.2 Volatility and investments

Different types of investments are more or less conducive to cooperation and thus more or less likely to be observed absent legal protection. The following proposition shows that a ceteris paribus increase in riskiness, in the sense of a mean-preserving spread, makes investment more difficult in the absence of legal protections (even with risk-neutral players).¹¹

Proposition 2 *Let the distribution G be a mean-preserving spread of F . Suppose that with returns characterized by the distribution G , there is a symmetric subgame perfect equilibrium in which Player 1 invests k . Then with returns characterized by the distribution F , there is also a symmetric subgame perfect equilibrium in which Player 1 invests k . Conversely, suppose that with returns characterized by F there is a symmetric subgame perfect equilibrium in which player 1 invests $k \neq k_d$. There may not be a subgame perfect equilibrium in which Player 1 invests k when returns are characterized by the distribution G .*

Proposition 2 provides a testable prediction of the model, which we explore in our experiment. We compare two treatments, one with a more volatile payoff structure than the other. In the less volatile all investment options we propose are part of an equilibrium, while in the other, an intermediate level is no longer part of an equilibrium (for the reasons outline above). We examine whether participants avoid choosing that investment level and if they don't, what do they revert to (no investment or higher investment levels).

To gain more intuition, consider a case where we start from a distribution of returns for which a particular investment is sustainable and take a series of mean-preserving spreads, we might arrive at a situation where such an investment is no longer possible. As an illustration, suppose that there are two players who discount at a rate $\delta = \frac{1}{2}$ and that in each period following Player 1's initial investment they play the following prisoner's dilemma.¹²

	C	D
C	$(\frac{3}{5}\hat{\pi}_t, \frac{2}{5}\hat{\pi}_t)$	$(0\hat{\pi}_t, \frac{3}{5}\hat{\pi}_t)$
D	$(\frac{4}{5}\hat{\pi}_t, 0\hat{\pi}_t)$	$(\frac{1}{10}\hat{\pi}_t, \frac{1}{10}\hat{\pi}_t)$

¹¹Similar reasoning shows that mean-preserving spreads makes collusion more difficult in the framework of Rotemberg and Saloner, although the way they model uncertainty does not allow them to reach this conclusion.

¹²Following the application in Section 2.3, we can interpret the game as one in which Player 1 is an innovative firm and Player 2 has the ability to copy the innovation costlessly. In order to compensate Player 1 for investing, when the players cooperate, Firm 2 restricts its output to give Firm 1 a larger share. To match this interpretation, the game is chosen to be asymmetric. This asymmetry plays no role, however.

We contrast two distribution functions. Under F , an investment of $k = 15$ yields a return of $\pi_t = 100$ in each period. Under G , an investment of 15 yields a period return of 300 with probability $\frac{1}{3}$ and 0 with probability $\frac{2}{3}$. In both cases, smaller investments yield 0 in every period and larger investments are of no benefit. With legal protections, these two technologies, which have the same mean, are equivalent for a risk-neutral agent, who will invest 15. Without protection, however, they are quite different.

First consider F . An investment of 15 followed by (C, C) in every period forms part of a stationary equilibrium. In any subgame, following the path yields Player 1 a total discounted payoff of $\frac{1}{1-\delta}60 = 120$, while deviating yields $80 + \frac{\delta}{1-\delta}10 = 90$. Player 2 also has no incentive to deviate. Moreover, Player 1's payoff from investing is $-15 + \frac{\delta}{1-\delta}60 = 45 > 0$.

Now consider the distribution G . Suppose the players try to play (C, C) repeatedly and consider a period in which a payoff of 300 has been realized. For Player 1, following the path yields $\frac{3}{5}(300) + \frac{\delta}{1-\delta}\frac{3}{5}E\pi = 240$, while deviating yields $\frac{4}{5}(300) + \frac{\delta}{1-\delta}\frac{1}{10}E\pi = 250$. Cooperation is no longer sustainable. The reason is that while the expected continuation payoff from cooperating under G is the same as under F , the instantaneous gain from deviating rises when a realization of 300 rather than 100 occurs.¹³ As a result, a positive investment is not possible under G .

This no-investment conclusion does not depend upon the fact that we have restricted ourselves to symmetric equilibria. If we drop this restriction, then new equilibria appear under F . For instance, an investment of 15 followed by (D, C) in period 1 and (C, C) in all subsequent periods forms part of an equilibrium. However, no new equilibria appear under G . That is, Player 1 does not invest even if we allow for asymmetric play. More generally, allowing for asymmetric equilibria would not affect the result of Proposition 2.¹⁴

This result has implications for the types of investments that should be observed in developing countries (application 1, described in section 2). In countries with weak property rights, investors worry about the risk of expropriation. Investments lead to random returns year to year and, as shown by Duncan (2006) in an empirical study of the mining industry, expropriations are much more likely in periods of price booms. Thus, an investor would be more likely to initially choose an investment leading to less volatile returns. In line with this idea, Dorsey et al. (2008) and Mikesell (1971) suggest that the share of FDI in minerals relative to petroleum is higher in countries with strong property rights (oil prices being less volatile than most minerals). This is of course only suggestive evidence and a more

¹³Here, limiting the maximum payoff by choosing $\bar{\pi} < 300$ does not help since this also proportionally reduces the continuation payoff.

¹⁴In any period with a realization π_t , the shape of the equilibrium affects the share of π_t each player obtains, but does not change the fact that it is a multiple of π_t . Thus, the proof of Proposition 2 would carry through.

systematic empirical test of Proposition 2 would be in order. This is precisely the purpose of our experiment, which tests this result by comparing two types of treatments where the distribution of returns can be ranked according to second order stochastic dominance.

3.3 Comparing the level of investment across legal regimes

We now compare the level of investment in environments where legal protection is available to the level in environments where it is not. However, this is often an ambiguous comparison, with some non-degenerate equilibria in the no-protection game involving more investment and some less. Rather than making a selection among equilibria, we examine a special case where unambiguous statements can be made. We find conditions under which all non-degenerate equilibria without legal protections involve more investment than with legal protections and conditions under which they all involve less. This special case yields testable predictions that we explore in our experiment.

When an investment which is feasible with legal protections is not sustainable without, there are two possible reasons. One is that, in order for Player 1 to recoup the investment, the players must cooperate but they do not manage to do so. The other is that, although the players could manage to cooperate, Player 1 does not earn enough to justify his investment. As we will see, in the first instance Player 1 responds by choosing a larger investment in order to facilitate cooperation, while in the second instance Player 1 responds by choosing a smaller investment so that less money needs to be recouped.

We now suppose that the stochastic investment process is such that, in any period, there is either a “failure” worth 0 or a “success” worth $\tilde{\pi}_m$. That is, the payoff variable π can only take one of two values, 0 or $\tilde{\pi}_m$. The initial investment k determines the likelihood $p(k)$ of obtaining $\tilde{\pi}_m$ in any single period.¹⁵

We parameterize the likelihood function p in two ways. First, we decompose Player 1’s investment into a fixed component H (which could be zero) that he must pay in order to have any productive capacity at all and a variable component. If player 1 pays the fixed cost H and an incremental amount k , then the probability of the realization $\tilde{\pi}_m$ in any period is $p(k) = mh(k)$, where $h : R^+ \rightarrow [0, 1)$, $h(0) = 0$, $h' > 0$, $h'' < 0$, and $m \in (0, 1]$. If $H > 0$ and Player 1 does not incur the fixed cost H , then $p(k) = 0$ for all k . Higher H ’s increase the minimum required investment, but have no effect on the marginal impact of additional investments above this requirement.

¹⁵Consider, for instance, the application of the model to innovation. For certain types of products, the nature of a successful innovation is not very variable and the investment level mainly influences the frequency of innovations. Examples include the case of upgrades of software or smartphones, where the issue is mostly one of frequency rather than quality. It may also be the case of the fashion industry (Raustiala and Sprigman, 2006), where a crucial factor is the speed of introduction of new collections.

Second, we use the variable m to parameterize the riskiness of the technology by writing a successful payoff as $\tilde{\pi}_m = \frac{\pi_0}{m}$ (m also parameterizes the probability $p(k) = mh(k)$). Thus, if Player 1 incurs the fixed cost H and makes an additional investment k , then, in any single period, with probability $p(k)$ the payoff variable $\pi = \tilde{\pi}_m = \frac{\pi_0}{m}$ and with probability $(1 - p(k))$ the payoff variable $\pi = 0$. Decreases in m induce a mean-preserving spread on the innovation process and have no effect on the expected per period revenue $p(k)\tilde{\pi}_m = h(k)\pi_0$.

With legal protections, the optimal *incremental* level of investment above H is independent of H , whenever this optimal level is greater than zero, and is independent of m . Formally, let $k^* = \arg \max \{-k - H + \frac{\delta}{1-\delta}p(k)\tilde{\pi}_m\} = \arg \max \{-k + \frac{\delta}{1-\delta}h(k)\pi_0\}$ and define $H' = -k^* + \frac{\delta}{1-\delta}h(k^*)\pi_0$. Then, with legal protections k^* is the optimal investment for all $(m, H) \in (0, 1] \times [0, H')$. For $(m, H) \in (0, 1] \times (H', \infty)$, the optimal investment is 0.

As noted, decreases in m induce a mean-preserving spread on the returns and have no effect on the equilibrium investment k^* in the game with protection. However, in the no-protection game the incremental investment k^* gets harder to sustain as m falls (Proposition 2). An investment of k^* that is sustainable for $m = 1$ may not be sustainable for smaller values of m . The following proposition shows that, for some parameters, all non-degenerate equilibria involve a greater investment than k^* .

Proposition 3 and 4 focus on situations where the reason for equilibrium breakdown is the failure to cooperate. It is useful to introduce the terminology *strict* equilibrium: an equilibrium in which all players strictly prefer following the path to deviating.

Proposition 3 *Fix H and suppose that for $m = 1$ there is a strict symmetric subgame perfect equilibrium in which Player 1 makes the incremental investment $k^* \neq k_d$. There exists values \underline{m} and \overline{m} ($\underline{m} < \overline{m} < 1$) such that:*

- *If $m \in [\overline{m}, 1]$, there exist subgame perfect equilibria where Player 1 invests more than, less than, or the same as k^* .*
- *If $m \in [\underline{m}, \overline{m}]$, any non-degenerate equilibrium involves higher investments than with protection: $k > k^*$.*
- *If $m \in [0, \underline{m}]$ the only equilibrium is the degenerate equilibrium.*

Moreover there are non-empty intervals on which such equilibria exist.

While future expected profits are unaffected by decreases in m , the instantaneous temptation to play non-cooperatively in a successful period increases, since the gain from a deviation is $(\beta_i - \alpha_i) \frac{\pi_0}{m}$. To counter this temptation, Player 1 increases his initial investment to increase future gains from cooperation. It is crucial that this increased investment raises the

probability of obtaining a high payoff, not (just) the value of this high payoff. As a result, the expected future returns to cooperation increase without affecting the instantaneous gains from deviating. Suppose that, on the contrary, investment raised the successful payoff without affecting its likelihood. That is, suppose we had $\bar{\pi} = \frac{\pi(k)}{m}$, with $\pi'(k) > 0$, and $p = mh$ for some $mh \leq 1$. Then, increased investment would raise both the future returns to cooperation and the instantaneous gains from deviating in offsetting fashion, and would not facilitate cooperation (or make it more difficult).

A different way of comparing investment levels across regimes is to use the cooperation ratio R . When $R \approx 0$, cooperation is impossible because the gains to cooperation are small relative to the one-period gain from deviating. Conversely, when $R \approx \infty$, cooperation is simple. More generally, as R decreases cooperation becomes more difficult.¹⁶ The following Proposition shows that, again, this may force Player 1 to invest more than k^* .

Proposition 4 *Fix H and m and suppose there is a strict symmetric subgame perfect equilibrium in which Player 1 makes the incremental investment $k^* \neq k_d$. There exists values \underline{R} and \bar{R} such that in the no-protection regime:*

- *If $R \in [\bar{R}, +\infty]$, there may exist subgame perfect equilibria where Player 1 invests more than, less than, or the same as k^* .*
- *If $R \in [\underline{R}, \bar{R}]$, any non-degenerate equilibrium involves higher investments than with protection: $k > k^*$.*
- *If $R \in [0, \underline{R}]$ the only equilibrium is the degenerate equilibrium.*

Moreover there are non-empty intervals on which such equilibria exist.

Propositions 3 and 4 present reactions to cooperation failures. As cooperation becomes more difficult to sustain, Player 1 responds by investing more, rendering cooperation easier. The following proposition involves a comparative static where cooperation is always possible but the issue is the investment condition. Now Player 1 responds by investing less so that he needs to recoup less money.

Proposition 5 *Let $H = 0$ and $m = 1$ and suppose there is a strict symmetric subgame perfect equilibrium in which Player 1 makes the incremental investment $k^* \neq k_d$. There exists an \hat{H} such that i) for all $0 \leq H \leq \hat{H}$, an incremental investment k^* remains part of an equilibrium and ii) for $H > \hat{H}$ every non-degenerate equilibrium involves an incremental investment $k < k^*$. Moreover there is a non-empty interval on which non-degenerate equilibria exist.*

¹⁶Note that varying R amounts to varying the shares $\alpha_i, \beta_i, \gamma_i, \lambda_i$.

4 Experimental Analysis

In this section, we present the design and results of a laboratory experiment tailored to achieve two goals. First, to test specifically some of the results of the theoretical analysis, in particular the effect of increased riskiness described in Proposition 2 and the possibility of higher levels of investment described in Proposition 3. Second, since a degenerate equilibrium always exists, to shed light on equilibrium selection issues and provide some empirical evidence on investment levels with and without legal protection.

4.1 Experimental setup

The experimental study is based on a series of infinitely repeated games. Participants play a series of supergames (matches), where each supergame corresponds to an infinitely repeated game. We implement four different experimental treatments. Two treatments correspond to an environment with legal protection of the stochastic outcome of investments (we refer to those as legal protection, LP, treatments) and two to an environment with no legal protection (we refer to those as no legal protection, NP, treatments). Within each regime (LP vs NP), we implement two different scenarios, corresponding to two different investment options. In a given treatment, there is a unique value of the return on investment (henceforth prize) and the investment affects the probability of obtaining this prize. In one option, there are relatively high probabilities of obtaining a low prize; in the other option, the prize is doubled and the probabilities are halved. We refer to the four treatments as LP-low-prize, LP-high-prize, NP-low-prize and NP-high-prize. The comparison between NP-low-prize and NP-high-prize is the main focus of our analysis: it allows us to test the result of Proposition 2.

We reproduce infinitely repeated games in the lab using a standard procedure involving a random continuation rule (see Dal Bo and Frechette 2011, Dal Bo 2005 and Casari and Camera 2009 for recent examples). Within each match, at the end of each round, the computer randomly determines whether or not another round will be played. The probability of continuation for each game is fixed at 0.85 for all treatments and is independent of any choices players make during the game. The players thus play a series of supergames of random length.

In the two LP treatments, all games are single-player games (there is no interaction with other players). In the first round of each game, the player first obtains an initial endowment of 11 tokens¹⁷ and makes an investment decision, choosing one among four possible investment levels: 0, 1, 6 or 11 tokens. This initial investment determines the probability of obtaining a prize in each round of the game but has no influence on the other games. The exact

¹⁷1 token is converted to 5 cents for the final payment.

probabilities and the level of the prize depend on the treatment as described in Table 1. *It is worth remarking that length of the match (supergame) is random, and is independent of the investment decision, even if Player 1 invested zero.*

In the NP treatments, each game involves two players: an investor (player 1) and a second player (player 2). At the beginning of the game, each player receives 11 tokens and one of them is randomly selected to be the investor (to avoid framing issues, in the experimental instructions we call the investor Role A and the second player Role B).¹⁸ In the first round, player 1 makes an investment decision with the same options as in the LP treatments (player 2 takes no action in the first round). In the subsequent rounds, whenever the investment is successful and a prize is obtained (the probability of success is determined by the decision of the investor in the first round), the two players play a prisoner’s dilemma game represented in Table 2 below.¹⁹

	<i>H</i>	<i>L</i>
<i>H</i>	$\frac{1}{2}\pi, \frac{1}{2}\pi$	$0, \pi$
<i>L</i>	$\pi, 0$	$0, 0$

Table 2

This set-up fits with our general framework, with $\alpha_i = 1/2$, $\beta_i = 1$, $\gamma_i = 0$ and $\lambda_i = 0$. At the end of each round in which a prize is obtained, each player observes the other player’s choice (*H* or *L*).

When a match (randomly) ends, a new one starts and is played in the same way. In the NP treatments, players are randomly re-matched with a different player. The rematching procedures works as follows: as soon as a pair finishes a match, each of its members is rematched with one player, randomly chosen from the first available pair (i.e., either a pair is already waiting or they have to wait for another pair to finish). This procedure guarantees that a subject doesn’t immediately play with the same partner and limits the likelihood of being matched with the same partner several times. In any case, the game is played anonymously and players cannot identify their partner. For the NP treatments (resp. LP), fifteen minutes (resp. ten minutes) after the start of the session, no new game starts but players finish the games they started.²⁰

¹⁸The roles are fixed throughout each match (supergame). When a match ends, rematching occurs and the types are redrawn for this new pair of players.

¹⁹In the LP treatments, whenever the investment is successful, the prize is obtained entirely by the single player. Nevertheless, to keep the two set of treatments symmetric, players in the LP treatment also have to choose whether they want to play high (*H*) or low (*L*) as in the NP treatment. The choice *L* gives them a profit of zero, and the choice they have to make is thus obvious, but it preserves symmetry with the NP treatments.

²⁰We did not put a time constraint on the games already started but they never lasted more than a few minutes.

4.2 Theoretical predictions

While our theoretical analysis focusses on symmetrical equilibria, nothing forces our experimental subjects to do the same. Indeed, the game we have chosen may even invite them to play asymmetrically as, say, alternating plays of (H, L) and (L, H) is myopically self-enforcing, as opposed to repeated plays of (H, H) . On the other hand, playing (H, H) is a simpler way to cooperate. It is interesting to see the extent to which the predictions of the model, restricted to symmetrical equilibria are borne out by the experiment.²¹

Our model allows us to make clear theoretical predictions. However, in practice, there will be noisy deviations from equilibrium behavior. We do not model explicitly the process creating this noise but assume that the distribution is the same in all treatments. This assumption allows us to derive a number of empirical predictions from the theory.

First, in both LP treatments, the optimal choice of a risk-neutral player is an investment level of 1, although the level of expected profits does not vary vastly across the different positive choices (12.6 for an investment of 1, 12.1 for 6 and 11.6 for 11).²²

In the case of the NP-low-prize treatment, an investment of 1 in the first round remains part of an equilibrium whereas in the NP-high-prize treatment it does not. Examining the incentives of the players (shown in Table 3), brings out clearly the mechanism developed in the theory. In both NP treatments, for an investment of 1, in the subgame following a successful realization of the investment, each player's continuation payoff is 6.8 if both of them play H for the rest of the game. However, in the low-prize treatment a player's instantaneous gain from deviating to L is only 4, while in the high-prize treatment it is 8, and cooperation is possible only with a low prize.

In the low-prize game, all investment levels form part of an equilibrium; in the high-prize game, all investment levels other than 1 form part of an equilibrium. We have the following clear prediction that can be tested:

- An investment of 1 is less likely in the NP-high-prize treatment than in the NP-low-prize treatment (special case of Proposition 2)

We can also test the consistency of the behavior in the stage prisoner dilemma game with the mechanism we propose:²³

²¹Recall also that one of the central predictions we test, i.e the result on mean preserving spreads is preserved under asymmetric equilibria.

²²While an investment of 1 is optimal for a risk-neutral money maximizer, subjects may have other motivations as well. For instance, they might get benefits from varying their choices to break the tediousness of the task.

²³These are not strictly speaking predictions, but are natural consequences of the model. For instance, in the NP-high-prize treatment, playing 1 is not an equilibrium, so interpreting what happens off the equilibrium path is not unambiguous. However, we know that in the subgame following a prize, player B should play L

- Following an investment of 1 by the investor, a play of L by player 2 is more likely in the NP-high-prize treatment than in the NP-low-prize treatment
- The probability of observing H, H increases with the initial investment of the investor

Finally, we can shed light on equilibrium selection issues and show evidence on the following questions:

- Is the zero investment degenerate equilibrium more common in the absence of protection (NP treatments)?
- Is there on average more or less investment with or without legal protections? Absent protection, is there more investment with a high prize or a low prize?

4.3 Experimental results

The 10 experimental sessions (3 of each NP treatments and 2 of each LP treatment) were run at the Ecole Polytechnique (France) in a dedicated experimental lab. A specific software was designed to run the experiment to be able to rematch players while others were finishing their game.²⁴ The participants were a mix of students and staff at the university. A total of 132 subjects participated in the experiment playing a total of 1756 games. The average earnings of players was 17.8 euros. At the end of the experiment, participants were asked to fill in a survey that allowed us to control for gender and whether the participants were students. In the survey, we also introduced questions about individuals' risk attitudes (Dohmen et al 2011). Thus, in some of our analysis we can also control for subjects self-reported risk attitudes.²⁵ In all the regression analysis that follow, the standard errors are clustered at the session level (as in Dal Bo and Frechette 2011 for instance), to control for possible session effects that would introduce correlation in errors.²⁶

²⁴The software was designed under a standard server/client architecture, the server uses' socket protocol to communicate with the clients. The server was implemented using the Adobe Flex technology and the clients deployed under Adobe Air. The backend of the server rely on relational database server (MySQL) for storing. Each "game" was considered as a thread, this method allowed us to resolve the main issue for rematching clients dynamically and keeping alive simultaneously other instances in progress.

²⁵Some participants did not fill in the survey which explains that regressions controlling for individual characteristics will be run on fewer observations.

²⁶We do not cluster at the individual level since the assumption in these type of environments is that each game can be considered as an individual observation. Note, however, that the significance of the main results is maintained if we do cluster at the individual level.

4.3.1 Testing the central theoretical prediction

The main theoretical prediction is that we should observe investors choosing a level of investment equal to 1 less often in the NP high-prize treatment than in the NP low-prize treatment. The theory does not, however, predict whether we should observe a reversal to the degenerate equilibrium or to a higher level of investment, and thus makes no prediction on the average investment level. The experimental evidence is then useful both to test the theoretical prediction and to shed light on equilibrium selection.

Figure 1 clearly shows that the difference between the low-prize and high-prize treatments is striking and goes in the direction suggested by the theory. Furthermore, Figure 2 suggests that learning strengthens this result. In the left panel we report the proportion of ones in the first game the players played and in the right the proportion in the later games. The proportion goes up for the low-prize treatments, while it slightly decreases in the high prize treatments. With learning, players move closer to equilibrium behavior, although there is always a non-negligible fraction that play non-equilibrium strategies.

We test the central prediction controlling for different factors. Table 4 reports the results of a probit regression of the probability of an investment of one by Player 1. The probability of observing an investment of one in the NP-low-prize treatment is significantly higher than in the NP-high-prize treatment. This result holds even when we control for individual characteristics and risk attitudes. A potential worry is that this result is not driven by our mechanism but by differences in the investors' perceptions of the two gambles. However, when the same comparison is run between the two LP treatments, the effect tends to go in the other direction: Figure 3 shows that in the case of legal protection of the investment, an investment of one is more likely in the high-prize treatments.²⁷ Thus, if any behavioral mechanism not considered by our theoretical framework was playing a role this would tend to go in the opposite direction with respect to our findings.

It is clear that in the high prize treatment, participants play 1 less often, but do they revert to not investing (the degenerate equilibrium)? In Figure 4, we present the full distribution of investment choices in the two NP treatments. We see that there is both an increase in the frequency of zero investment and in the frequency of the maximum investment level. Importantly, average investment is 13% higher in the NP-high-prize treatment and this difference is significant (p-value of 0.03 in a t-test). Consistent with our theoretical predictions, taking a mean-preserving spread of the distribution leads to more investment on average.

²⁷A regression analysis confirms that the effect is significant.

4.3.2 Cooperative behavior

The results of the previous section provide strong support for the central prediction of the theory. To further test the coherence of our explanation, in this section we examine the cooperative behavior of the investors and the other players whenever a prize is obtained.

We first focus on the cooperative behavior in games where Player 1 chooses one token. Figure 5 represents the distribution of outcomes in the prisoner's dilemma keeping in each game only the first round where a prize is obtained (the plot averaging over all rounds looks very similar). We clearly see that the outcome LL where both players choose to defect in the stage prisoner dilemma is much more likely in the high-prize treatment than the low-prize treatment as the theory suggests: the temptation to deviate is much larger.

It is, of course, not easy to interpret the actions chosen in the stage prisoner dilemma game following an investment that should not occur in equilibrium. In particular, why would the investor make a positive investment choice if he then expects LL to be the most likely outcome? It may therefore be more natural to focus on the behavior of the player 2's following an investment of 1 by the investor. The results presented in Figure 6 are even more striking: a player 2 is much more likely to choose L in the high-prize treatments than the low prize treatments.²⁸ The results presented in table 5 confirm the pattern observed in Figure 6. Even when controlling for individual characteristics, there is a significantly lower chance that a player 2 plays L following an investment of one in the low-prize treatment.

A final test of coherence with the theory is to examine the cooperative behavior by level of investment of the investor. The more he invests, the higher the expected continuation value in equilibrium if HH is played whenever a prize is obtained and thus the higher the incentives to keep cooperating (Table 3 shows how much the incentives to deviate decrease as the initial investment increases). We thus plot in Figure 7 the behavior of player 2 in the NP-high-prize treatments, separately for investments of 1, 6 and 11. There is a clear rise in the proportions of H 's as the investment moves from 1 to 6, although no significant change as the investment goes from 6 to 11. Note that this fits with the results in the literature showing that cooperation rates increase when the discount factor increases (Dal Bo 2005 or Dal Bo and Frechette 2011).

4.3.3 Investment with legal protection vs. investment without protection

Comparing the level of investment in an environment such as the one described in our theoretical analysis with and without legal protection based on real world data is hard for the

²⁸For Figure 5 and 6 and table 5, we keep in each game only the first round where a prize is obtained provided it exists.

simple reason that counter-factuals are hard to come by. Experiments creating artificial counter-factuals are thus a valuable source of evidence to shed light on this comparison. We find that the average investment is slightly higher in the absence of protection (average of NP treatments) than in its presence (average of LP treatments), but this difference is not significant (p-value of 0.149 in a t-test and non significant coefficient in a regression controlling for individual characteristics). This indicates that relatively high levels of investment are possible even without legal protection as suggested in the theoretical section. The main focus of the experiment is to test the mechanism we propose.

Taken together, the results of the experiment provide evidence broadly coherent with our theoretical model. Investors are less likely to choose the investment level of one in the high-prize treatments in the absence of legal protection and, when they do, player 2's are more likely to defect (choose action L) in the stage prisoner dilemma game. Furthermore, the overall results provide evidence that investment in the absence of protection (NP treatments) and with perfect legal protection (LP treatment) are quite similar.

5 Conclusion

Our theory of investment and cooperation in the shadow of future interactions has multiple possible applications. In particular, our central results can be summarized in the context of a specific example, that of the firm Red Hat. Red Hat, a hugely successful company, was created in 1993. At its stock market introduction, Red Hat was one of the biggest IPOs in the NASDAQ and, since 2009, has been part of the S&P500, with over 3000 employees and revenues of over 500 million dollars. For many, this success is puzzling, since the company's business model is based on open source software. Most of Red Hat's revenues come from the sale to companies of subscriptions, including their own pre-compiled version of the open source operating system Linux, called Red Hat Enterprise Linux, and support services.²⁹ Two facts are particularly striking. First, as acknowledged in Red Hat's annual report: "anyone can copy, modify and redistribute Red Hat Enterprise Linux (...) however they are not permitted to refer to these products as Red Hat". Numerous clones do indeed exist, but they appear to avoid competing aggressively and do not gain much market share. Second, in spite of a potentially extremely competitive environment, Red Hat invests a lot in research. According to a report from the Linux Foundation, Red Hat is the biggest single contributor to the Linux Kernel (excluding unaffiliated contributors), and pays the salaries of many of the top contributing individuals.

²⁹According to Red Hat's annual report, the revenues from subscriptions in 2010 were \$541M out of a total revenue of \$652M.

Our model can explain such behavior. On the equilibrium path, Red Hat's clones, rationally choose not to be too aggressive.³⁰ This can be part of an equilibrium only if Red Hat invests sufficiently in research. In the spirit of our Proposition 2, the type of environment in which Red Hat operates seems particularly well adapted for investment in the absence of protection since it involves many small incremental innovations (high probability of obtaining small returns). Of course this claim is tricky to establish empirically. This is the main justification for conducting the laboratory experiment that broadly confirms our results.

Greif (1989 and 1993) finds that social norms in medieval times were able to sustain long-distance trade in the absence of contract enforcement by courts. Our model suggests an informal arrangement complementary to the one developed by Greif, and suggests, moreover, that trade might have been even more intense because of the absence of legal rules. Merchants needed to keep the promise of the future high to keep intermediaries cooperative. Interestingly, the model suggests that the merchants would not send bigger ships (which would leave the incentives to deviate unchanged) but more robust ones having higher chances of reaching their final destination.

³⁰The manager of a clone declared in an interview, "We have the utmost respect for Red Hat and everything they have done for the community over the years. We have absolutely no desire to upset them" (Kerner 2005).

6 Appendix

Proof of Proposition 1. Part *a* of the proposition is immediate. For Part *b*, suppose there exists a value $\tilde{\pi}$ and an investment k such that conditions (2) and (3) hold and let Player 1 choose $\bar{\pi} = \tilde{\pi}$ in Period 0 along with an investment k . Consider an equilibrium path in which all the players play *C* forever with a threat of *D* forever (the worst punishment) if anyone deviates (including Player 1 initially deviating to a different choice of k). Suppose that in period t the realization of the payoff variable is π_t and recall that $\hat{\pi}_t = \min\{\pi_t, \bar{\pi}\}$. Starting in period t , following the path yields a player (for $i = 1$ or o)

$$\alpha_i \hat{\pi}_t + \alpha_i \frac{\delta}{1-\delta} \left(\int_0^{\bar{\pi}} \pi dF(\pi, k) + \bar{\pi} (1 - F(\bar{\pi})) \right)$$

while deviating yields

$$\beta_i \hat{\pi}_t + \lambda_i \frac{\delta}{1-\delta} \left(\int_0^{\bar{\pi}} \pi dF(\pi, k) + \bar{\pi} (1 - F(\bar{\pi})) \right)$$

All players will follow the path if

$$\begin{aligned} (\beta_i - \alpha_i) \hat{\pi}_t &\leq (\alpha_i - \lambda_i) \frac{\delta}{1-\delta} \left(\int_0^{\bar{\pi}} \pi dF(\pi, k) + \bar{\pi} (1 - F(\bar{\pi})) \right) \text{ for } i = 1 \text{ and } o \\ \text{iff } \hat{\pi}_t &\leq \frac{\delta}{1-\delta} R \left(\int_0^{\bar{\pi}} \pi dF(\pi, k) + \bar{\pi} (1 - F(\bar{\pi})) \right) \end{aligned}$$

which holds from condition (2), since $\hat{\pi}_t \leq \bar{\pi} = \tilde{\pi}$. Player 1's overall payoff will then be:

$$-k + \frac{\delta}{1-\delta} \alpha_1 \left(\int_0^{\bar{\pi}} \pi dF(\pi, k) + \bar{\pi} (1 - F(\bar{\pi})) \right)$$

From condition (3), this expected payoff is larger than the payoff from choosing a different value of k since the other players play *D* forever in that case. Therefore conditions (2) and (3) guarantee that a subgame perfect equilibrium with investment $k > k_d$ exists.

Conversely, for given k , let $\tilde{\pi}_{\max} = \{\sup \tilde{\pi} \text{ s.t. 2 holds}\}$ (we showed in the main text that $\tilde{\pi}_{\max}$ exists). Then $\tilde{\pi}_{\max}$ is an upperbound on the single period payoff on which the players can cooperate. If:

$$-k + \frac{\delta}{1-\delta} \alpha_1 \left(\int_0^{\tilde{\pi}_{\max}} \pi dF(\pi, k) + \tilde{\pi}_{\max} (1 - F(\tilde{\pi}_{\max})) \right) < -k_d + \frac{\delta}{1-\delta} \lambda_1 \int_0^{\infty} \pi dF(\pi, k_d)$$

then Player 1 will prefer to invest k_d to k . ■

Proof of Proposition 2. Suppose that under G there is a symmetric subgame perfect equilibrium in which Player 1 invests k . From Proposition 1 there is a $\tilde{\pi}$ such that

$$\tilde{\pi} \leq \frac{\delta}{1-\delta} R \left(\int_0^{\tilde{\pi}} \pi dG(\pi, k) + \tilde{\pi} (1 - G(\tilde{\pi})) \right)$$

and

$$-k + \frac{\delta}{1-\delta} \alpha_1 \left(\int_0^{\tilde{\pi}} \pi dG(\pi, k) + \tilde{\pi} (1 - G(\tilde{\pi})) \right) \geq -k_d + \frac{\delta}{1-\delta} \lambda_1 \int_0^{\infty} \pi dG(\pi, k_d)$$

Integrating by parts, we can rewrite these conditions as:

$$\tilde{\pi} \leq R \frac{\delta}{1-\delta} \left(\tilde{\pi} - \int_0^{\tilde{\pi}} G(\pi, k) d\pi \right)$$

and

$$-k + \frac{\delta}{1-\delta} \alpha_1 \left(\tilde{\pi} - \int_0^{\tilde{\pi}} G(\pi, k) d\pi \right) \geq -k_d + \frac{\delta}{1-\delta} \lambda_1 \int_0^{\infty} \pi dG(\pi, k_d)$$

Since G is a mean-preserving spread of F , F second order stochastically dominates G . From the definition of second order stochastic dominance,

$$\left(\tilde{\pi} - \int_0^{\tilde{\pi}} G(\pi, k) d\pi \right) \leq \left(\tilde{\pi} - \int_0^{\tilde{\pi}} F(\pi, k) d\pi \right).$$

Hence,

$$\tilde{\pi} \leq R \frac{\delta}{1-\delta} \left(\tilde{\pi} - \int_0^{\tilde{\pi}} F(\pi, k) d\pi \right)$$

and

$$\begin{aligned} -k + \frac{\delta}{1-\delta} \alpha_1 \left(\tilde{\pi} - \int_0^{\tilde{\pi}} F(\pi, k) d\pi \right) &\geq -k_d + \frac{\delta}{1-\delta} \lambda_1 \int_0^{\infty} \pi dG(\pi, k_d) \\ &= -k_d + \frac{\delta}{1-\delta} \lambda_1 \int_0^{\infty} \pi dF(\pi, k_d) \end{aligned}$$

Thus, a choice of k is also sustainable under F . Conversely, we give an example in the main text showing that some investments $k \neq k_d$ can be part of an equilibrium under F and not under G . ■

Proof of Proposition 3. We can rewrite the conditions of Proposition 1 for an investment k as:

$$\frac{\pi_0}{m} \leq \frac{\delta}{1-\delta} R m h(k) \frac{\pi_0}{m} \Leftrightarrow \frac{1}{m} \leq \frac{\delta}{1-\delta} R h(k) \quad (4)$$

and

$$-k + \frac{\delta}{1-\delta}\alpha_1\pi_0h(k) \geq -k_d + \frac{\delta}{1-\delta}\lambda_1\pi_0h(k_d) \quad (5)$$

Let \bar{m} be defined by:

$$\frac{1}{\bar{m}} = \frac{\delta}{1-\delta}Rh(k^*)$$

For $m > \bar{m}$, the cooperation constraint (4) is satisfied. Given that k^* is part of an equilibrium for $m=1$, the investment constraint (5) is also satisfied. So, as stated in the Proposition 1, k^* is a subgame perfect equilibrium and so are some values k larger and smaller than k^* .

For $m < \bar{m}$, the cooperation constraint (4) evaluated at k^* is violated, so that following an investment of $k \leq k^*$ the players play non-cooperatively and the only possible equilibrium with $k \leq k^*$ is the degenerate equilibrium, where Player 1 chooses $k = k_d$.

There is however a range of values such that some investments strictly above k^* are part of an equilibrium. Define \underline{m} as:

$$\frac{1}{\underline{m}} = \frac{\delta}{1-\delta}Rh(\underline{k})$$

where \underline{k} is such that:

$$-\underline{k} + \frac{\delta}{1-\delta}\alpha_1\pi_0h(\underline{k}) = -k_d + \frac{\delta}{1-\delta}\lambda_1\pi_0h(k_d)$$

Given this definition, for $m \geq \underline{m}$, an investment of $\underline{k} > k^*$ is part of a subgame perfect equilibrium. This establishes the second result of the Proposition.

Finally, for $m < \underline{m}$, the only non-degenerate equilibria would involve investments above \underline{k} . We show below that this would lead to negative profits and cannot therefore be an equilibrium. Thus, for this region, the only subgame perfect equilibrium is the degenerate equilibrium.

Define:

$$G(k) = -k + \frac{\delta}{1-\delta}\alpha_1\pi_0h(k) - \left(-k_d + \frac{\delta}{1-\delta}\lambda_1\pi_0h(k_d) \right)$$

We know $G(k^*) > 0$, $G(\underline{k}) = 0$, and because $G'' < 0$, this implies that $G' < 0$ for $k > \underline{k}$. Thus $G(k) < 0$ for $k > \underline{k}$ ■

Proof of Proposition 4. The proof follows the same lines as the proof of Proposition 3. Given the distribution function at hand, the condition for cooperation can be rewritten as $\tilde{\pi} \leq \frac{\delta}{1-\delta}Rp(k^*)\tilde{\pi}$. Let \bar{R} be defined by $1 = \frac{\delta}{1-\delta}\bar{R}p(k^*)$. Since k^* forms part of a strict equilibrium, $\min_i \left[\frac{\bar{\alpha}_i - \bar{\lambda}_i}{\bar{\beta}_i - \bar{\alpha}_i} \right] > \bar{R}$ and $-k^* + \frac{\delta}{1-\delta}\bar{\alpha}_1p(k^*)\tilde{\pi} > -k_d + \frac{\delta}{1-\delta}\bar{\lambda}_1p(k_d)\tilde{\pi}$. By continuity, there are parameters $\alpha_i, \beta_i, \gamma_i$, and λ_i for which $R > \bar{R}$ and Player 1 invests more than k^*

and parameters for which he invests less. In these equilibria, the other players threaten to play non-cooperatively if Player 1 does not make the “appropriate” investment.

If $R < \bar{R}$, investing k^* can no longer be part of an equilibrium since the players will play non-cooperatively following an investment k^* . To induce the players to play cooperatively, a higher level of investment needs to be made. Again, by continuity there are parameter values for which $R < \bar{R}$ and a higher investment forms part of an equilibrium.

Finally, let $G(k) = -k + \frac{\delta}{1-\delta}p(k)\tilde{\pi}$. Notice that, $G(0) = 0$ and $G(k^*) > 0$. Since $G'' < 0$ and $G(\frac{\delta}{1-\delta}\tilde{\pi}) < 0$, there exists a $\hat{k} > k^*$ such that $G(\hat{k}) = 0$ and $G(k) < 0$ for all $k > \hat{k}$. Define \underline{R} by $1 = \frac{\delta}{1-\delta}Rp(\hat{k})$. For $R < \underline{R}$, cooperation is possible only if $k > \hat{k}$. But Player 1 cannot recoup such an investment since, for all $k > \hat{k}$ and α_1 , $-k + \alpha_1\frac{\delta}{1-\delta}p(k)\tilde{\pi} < G(k) < 0$. Thus, in this region, the only subgame perfect equilibrium involves an investment $k = k_d$. ■

Proof of Proposition 5. Since k^* is a strict equilibrium for $H = 0$, $-k^* + \frac{\delta}{1-\delta}\bar{\alpha}_1p(k^*)\tilde{\pi} > -k_d + \frac{\delta}{1-\delta}\bar{\lambda}_1p(k_d)\tilde{\pi}$. Let \hat{H} be defined by $\hat{H} = -k^* + \frac{\delta}{1-\delta}\lambda_1p(k^*)\pi$. For $0 \leq H \leq \hat{H}$, an investment of the fixed cost H plus the variable cost k^* remains part of an equilibrium. For $H > \hat{H}$, a variable investment of k^* is not part of an equilibrium, since $-k^* - H + \frac{\delta}{1-\delta}\lambda_1p(k^*)\pi < 0$. Moreover, neither is any variable investment $k > k^*$ since $\frac{d}{dk}(-k^* - H + \frac{\delta}{1-\delta}\lambda_1p(k^*)\pi) = -1 + \frac{\delta}{1-\delta}\lambda_1p'(k^*)\pi < -1 + \frac{\delta}{1-\delta}p'(k^*)\pi = 0$ and $\frac{d^2}{dk^2}(-k - H + \frac{\delta}{1-\delta}\lambda_1p(k)\pi) < 0$. Since k^* is a strict equilibrium, $1 < \frac{\delta}{1-\delta}Rmh(k')$. Let $k' < k^*$ be defined by $1 = \frac{\delta}{1-\delta}Rmh(k')$ and H' be defined by $-k' - H' + \frac{\delta}{1-\delta}\lambda_1p(k')\pi = 0$. For all $H \in (\hat{H}, H')$, an investment of k' forms part of an equilibrium. ■

Table 1: Investment options in high vs low prize treatments

	Low-prize treatments		High-prize treatments	
Investment	Prize	Probability	Prize	Probability
0	8	0	16	0
1	8	0.3	16	0.15
6	8	0.4	16	0.2
11	8	0.5	16	0.25

Table 2: Stage prisoner's dilemma experimental game

	H	L
H	$\Pi/2, \Pi/2$	$0, \Pi$
L	$\Pi, 0$	$0, 0$

Note: $\Pi = 8$ for the low-prize treatments and $\Pi = 16$ for the high-prize treatments

Table 3: Profits and deviation incentives in NP treatments

	Low-prize treatments		High-prize treatments	
Investment	Expected profits of player 1	Deviation incentive	Expected profits of player 1	Deviation incentives
1	10.8	-2.8	14.8	1.2
6	13.1	-5.1	17.1	-1.1
11	15.3	-7.3	19.3	-3.3

NOTE: Expected profits of player 1 calculated under the assumption that (H, H) is played whenever a prize is obtained. Deviation incentives is the difference between the prize (i.e deviation profits) and the expected profits if (H, H) is played whenever a prize is obtained (i.e expected profits on equilibrium path). A positive value for the deviation incentives means that level of investment cannot be part of an equilibrium.

Table 4: Probability of observing investment of 1 by player 1 in NP treatments

	(1)	(2)	(3)
Low prize treatment	.37**	.29**	.37*
	(.15)	(.13)	(.21)
Individual controls (except risk)	no	yes	yes
All controls	no	no	yes
Number of observations	947	893	893

NOTE: This table reports the coefficients of a probit regression. The dependent variable is a dummy taking the value 1 if an investment of 1 was made. The main explanatory variable is a dummy taking value 1 for low prize treatments. Column (1) does not control for individual characteristics, column (2) controls for socio economic characteristics and column (3) adds risk aversion. We restrict the sample to NP treatments. Standard errors clustered at the session level in parentheses. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level

Table 5: Probability of player 2 playing L in games where player 1 invested 1

	(1)	(2)	(3)
Low prize treatment	-.44	-.36	-.71**
	(.38)	(.31)	(.36)
Individual controls (except risk)	no	yes	yes
All controls	no	no	yes
Clustered standard errors	no	no	no
Number of observations	183	171	167

NOTE: This table reports the coefficients of a probit regression. The dependent variable is a dummy taking the value 1 if player 2 played L . The main explanatory variable is a dummy taking value 1 for low prize treatments. Column (1) does not control for individual characteristics, column (2) controls for socio economic characteristics and column (3) adds risk aversion. We restrict the sample to observations corresponding to the first time a prize is obtained in the game (provided it exists). Standard errors clustered at the session level in parentheses. ***Significant at the 1 percent level, **Significant at the 5 percent level, *Significant at the 10 percent level

Figure 1:

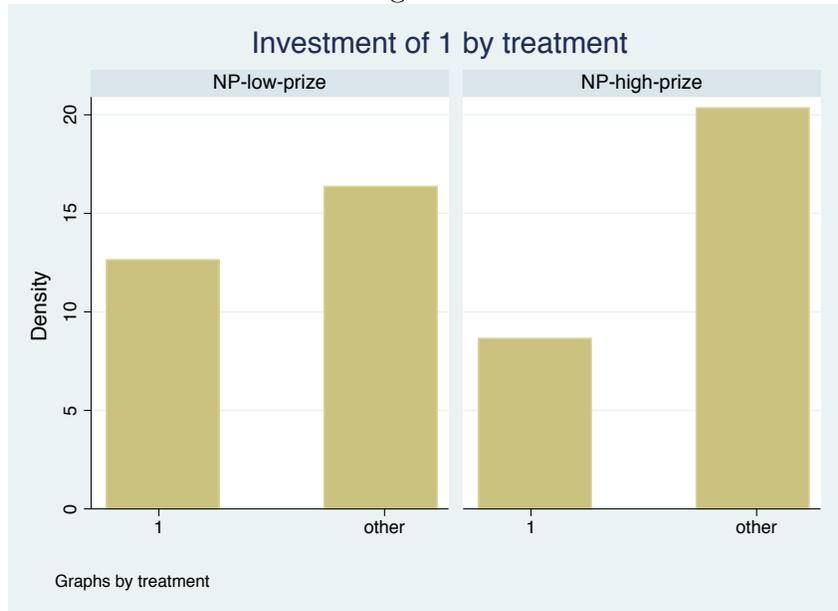


Figure 2:

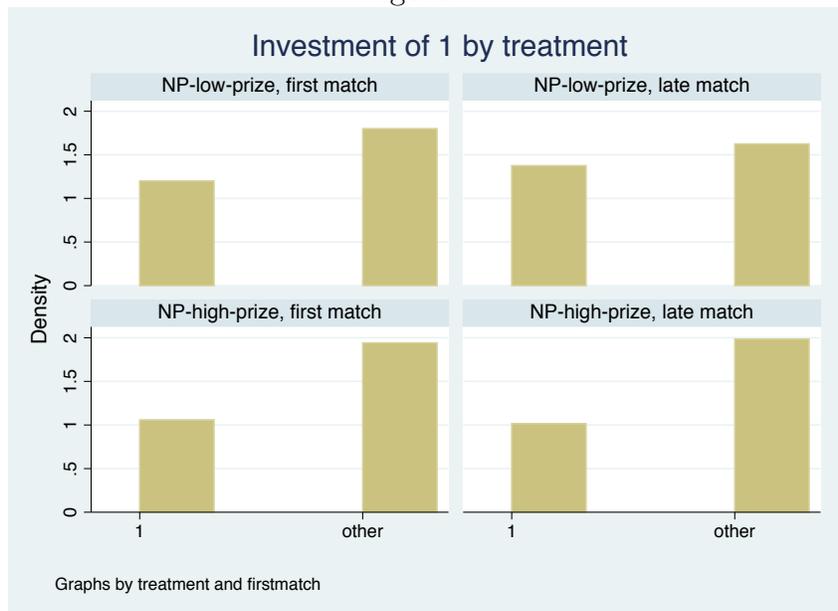


Figure 3:

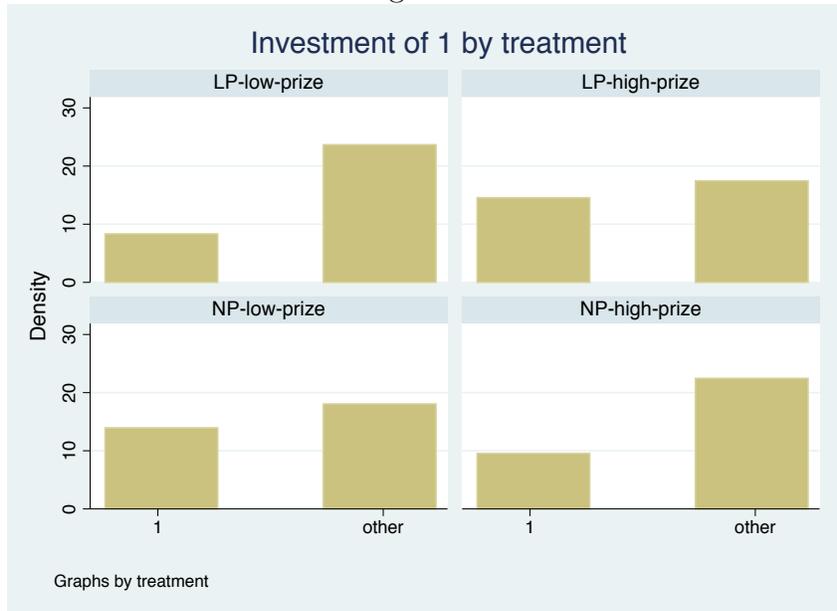


Figure 4:

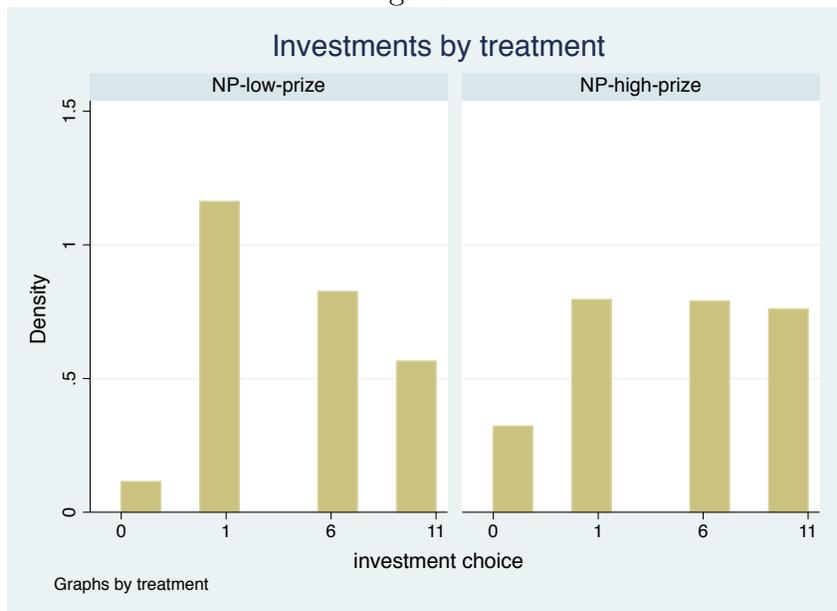


Figure 5:

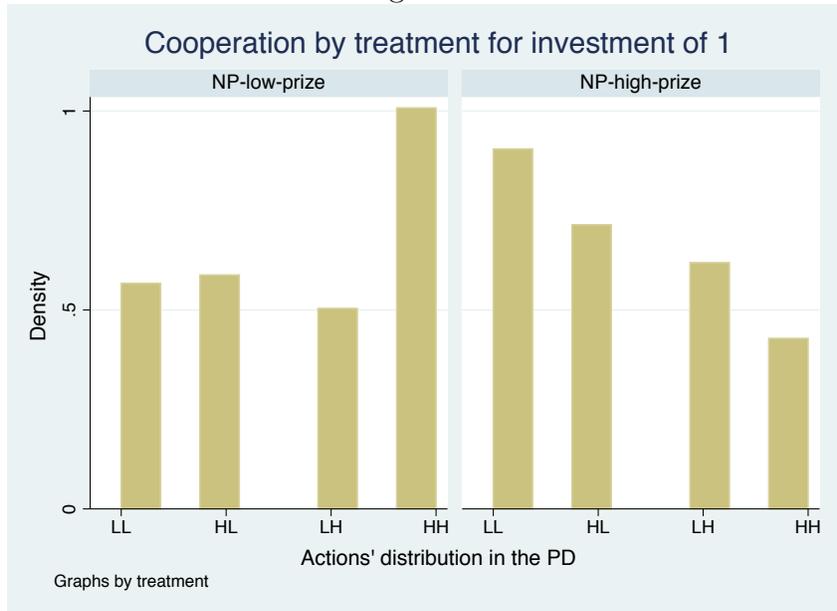


Figure 6:

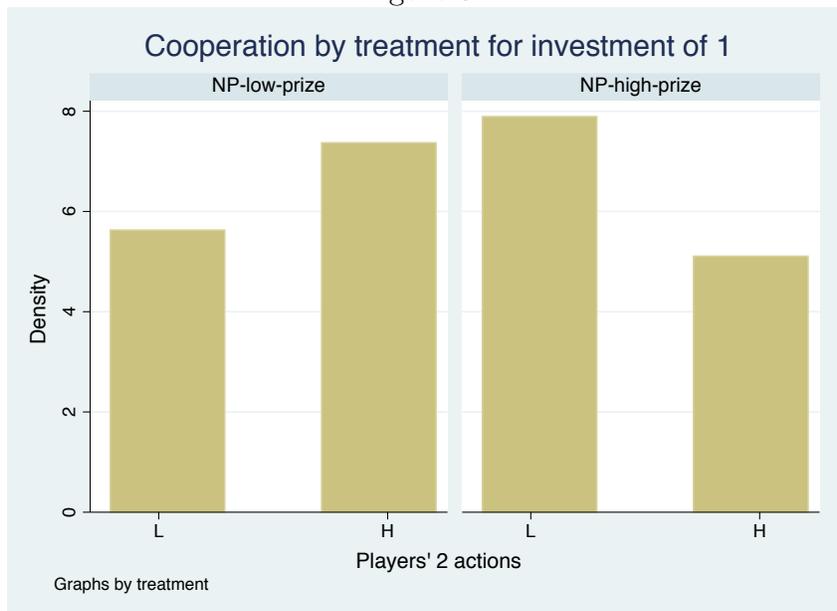


Figure 7:



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