Investing to cooperate: theory and experiment[*] [†]

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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 more volatile returns make investment more difficult in the absence of legal protection, and might force the investor to invest more to guarantee cooperation. Experimental results are broadly consistent with the theoretical findings.

JEL: C72, C73, C91, C92

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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 all these examples involving an investment decision, legal protection being weak or absent, the incentive to initially invest might appear weak. However, these investments are typically embedded in a dynamic environment where the parties involved keep interacting. In this context, the disciplining value of repeated interactions can serve as a substitute for legal environments. In this setting, we explore theoretically and empirically how the levels of investment differ depending on the legal regime and how they compare when we vary a particular characteristic of the environment, namely the volatility of returns.

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To understand the role of volatility, consider two distributions of returns F and G where G is a mean preserving spread of F. Because these two distributions generate the same expected profits, risk neutral agents would make the same investments in a legal regime, whether they face F or G. On the other hand, in a regime without legal protection, large returns make cooperation through repeated interactions harder to sustain since the temptation to deviate are higher while the promise of the future is kept constant. Such large returns are more likely to arise under distribution G, thus potentially forcing the investor to initially invest more to sustain cooperation.

We run an experiment designed to capture such environments and study the investment decision. We adopt a 2x2 design where we vary both the legal regime (either legal protection LP or no protection NP) and the shape of returns from investment (either low volatility LV or high volatility HV). Participants play a series of games of indefinite length, generated using a random continuation rule. In all treatments, in the first round of each game, the player in the role of investor chooses an investment level which can either be zero or one of 3 possible positive values. This initial investment determines, in each period of the indefinitely repeated game that follows, the probability of getting a prize of fixed value. In the legal protection treatments, whenever a prize is obtained, the investor obtains the full value. In the no protection treatments, the investor faces in all subsequent rounds another player and when a prize is obtained, the two players play a symmetric prisoner's dilemma where if both players cooperate they share the prize.

In the high volatility (HV) treatments, for all levels of investment, the value of the prize is twice as high as in the low volatility (LV) treatments, but the probability of obtaining it is twice as low. The distribution of returns in the HV treatments is thus a mean preserving spread of the distribution in LV. Under legal protection, the optimal investment is the same regardless of the volatility of returns since the expected return is unaffected.

In the particular case of the experiment, we show that our theoretical results imply that in the LV treatments without legal protection, all investment levels are part of an equilibrium, while in the HV treatment, an investment of 1 (the optimal level of investment with protection) is no longer an equilibrium. Empirically, we show that indeed an investment of 1 is significantly less likely in the HV treatment. We have therefore identified circumstances under which all equilibria with positive levels of investment involve more investment in the absence of protection. The reason is that higher initial investments shift up the distribution of future returns, thereby facilitating cooperation as the future returns to cooperation increase.[1] Coherently with the theoretical model we find that, if Player 1 happens to invest 1 in the NP-HV treatment, it is more likely to be followed by deviations in the prisoner's dilemma that follows, in particular by Player 2.

Furthermore we find that in our experiment, the average level of investment is slightly higher in the treatments without protection, in particular in the case where returns are volatile. Indeed, in the NP-HV treatment, both the zero investment outcome and strictly higher levels of investments

[1]Note 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.

become more likely, suggesting that some participants revert to the degenerate equilibrium – no investment/ no cooperation – while others choose to invest more to foster cooperation. The overall level of investment is left unaffected. Even though this does not correspond to a theoretical prediction, it shows that strong protection does not necessarily increase investment levels.

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.[2] However, while this literature 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 theoretically 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.

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

[2]Indeed we will find that cooperation is higher when the investor invested more initially.

interest rate fluctuates.[3]

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 are presented in the appendix.

2 Experimental design

We run an experiment designed to capture the effect on investment decisions of the legal regime and, within each regime, the effect of the distribution of returns. We therefore adopt a two by two design, giving 4 different treatments, with either legal protection (LP) or no legal protection (NP) and with either high volatility of returns (HV) or low volatility (LV).

In all treatments, the length of each game is determined by a random continuation rule following closely the literature on indefinitely repeated games in the lab (see Dal Bo and Frechette 2011, Dal Bo 2005 and Casari and Camera 2009 for recent examples). Within a game, at the end of each round, the computer randomly determines whether or not another round will be played in the current game. The probability of continuation is fixed at 0.85 for all treatments and is independent of any choices players make during the game.[4] The players thus play a series of games (that we call matches) of random length.

In all treatments, in the first round of each match, the player in the role of investor first obtains an initial endowment of 11 tokens[5] and makes an investment decision, choosing one among four possible investment levels: 0, 1, 6 or 11 tokens. This initial investment determines, in each round of the match, the probability of obtaining a prize, but has no influence on the other games.

The first difference between treatments lies in the distribution of returns on investment. In the high volatility treatments (HV), the prize is twice as high as in the low volatility treatments (LV), but for all levels of investment, the probability of obtaining the prize is twice as low. The expected return for a given investment thus remains constant across treatments. The exact probabilities and the level of the prize are detailed in Table 3. 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.

The second difference is what regime is in place in periods where a prize is obtained. In the legal protection treatments (LP), the investor keeps the entire prize. The matches in the LP treatments are thus single player games. On the contrary, in the no legal protection treatments

[3] Our theoretical and experimental results can also speak to the renewed debate on the use of patents to encourage investments in innovation (Boldrin and Levine 2008, Bessen and Hunt 2007, Scherer and Ross 1990, Benoît 1985, Henry and Ponce 2011, Henry and Ruiz-Aliseda 2016, 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.

[4] This intermediate value of δ will guarantee that some investments are part of equilibria under NP-LV but not under NP-HV.

[5] 1 token is converted to 5 cents for the final payment.

Table 1: Prisoner's dilemma when a prize is obtained

	C	D
C	$\frac{1}{2}\pi, \frac{1}{2}\pi$	$0, \pi$
D	$\pi, 0$	$0, 0$

(NP), in a round where a prize is obtained, the investor (player 1) faces a second player (player 2) and the two players play a prisoner's dilemma game represented in Table 1.[6]

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. When they are rematched, it is randomly determined which player plays the role of the investor. The rematching procedure 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.[7]

3 Model

In this section, we present a formal model, that is general enough to encompass many scenarios of interest, and allows us in particular to make predictions that we test using our experimental setup. In the next section, we provide several applications.

We consider an infinite horizon game with two players where periods are denoted by t and future payoffs are discounted at rate δ by all players. In period 0, Player 1 makes an initial investment k at cost $c(k)$. The size of this initial investment stochastically affects the payoffs in subsequent periods. 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 and that corresponds to the LP treatments, in period $t \geq 1$ player 1 mechanically collects the payoff realization π_t while the other player earns 0. Player 1 chooses an investment level that maximizes her total expected discounted

[6]In 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 C or D as in the NP treatment. The choice D gives them a profit of zero, and the choice they have to make is thus obvious, but it preserves symmetry with the NP treatments.

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

Table 2: Prisoner's dilemma

	C	D
C	$\alpha\hat{\pi}_t, \alpha\hat{\pi}_t$	$\gamma\hat{\pi}_t, \beta\hat{\pi}_t$
D	$\beta\hat{\pi}_t, \gamma\hat{\pi}_t$	$\lambda\hat{\pi}_t, \lambda\hat{\pi}_t$

profits. That is, Player 1 chooses k (in period 0) to maximize $-c(k) + \sum_{t=1}^{\infty} \delta^t \int_0^{\infty} \pi dF(\pi, k) = -c(k) + \frac{\delta}{1-\delta} E(\pi|k)$, 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, corresponding to the NP treatments, following her initial investment, player 1 engages in an infinite horizon game with another player we denote player 2. 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 $\overline{\pi}$ that the variable π can take. We allow that $\overline{\pi}$ can be chosen to be ∞, so that no constraint is imposed. Note also that in the experiment $\overline{\pi}$ plays no role.

More precisely, the players engage in the following game:

- In period $t = 0$, Player 1 chooses $k \geq 0$ and $\overline{\pi} \in (R_+, \infty)$.
- 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.
- Payoffs are described by the payoffs in Table 2, where $\hat{\pi}_t = \min(\pi_t, \overline{\pi})$:

  We assume $\beta > \alpha$, $\lambda \geq \gamma$, $\lambda < \alpha$, and $1 > \beta$.[8] 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 $\beta < 1$ ensures that Player 1 always does worse in the absence of legal protection.

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.

[8] In our experiment $\alpha = 1/2$, $\gamma = \lambda = 0$ and $\beta = 1$.

For all individuals, $\alpha - \lambda$ provides a measure of the gains from cooperating, while $\beta - \alpha$ 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:

$$R \equiv \left[\frac{\alpha - \lambda}{\beta - \alpha}\right]$$

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.

3.1 Applications of the model

3.1.1 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) and can also impact the type of sectors attracting investments. 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 production that the investment can generate. In each period that follows, the government decides whether or not to expropriate the firm. In the Supplementary Appendix C, we propose a precise parametrization of the payoffs of the different players.

3.1.2 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 parties. Consumption at a high level imposes significant costs, so that all players consuming at a high level is unsustainable for that period.[9]

[9] As written, this model does not take into account the dynamics of overuse of the public good in the sense that

3.1.3 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, a very successful company selling an open source operating system and investing heavily in research. 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. 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 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 an imitator, such as Red Hat and a clone. 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.[10] 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.[11]

4 Investing to cooperate

We now derive our main results, presenting in sections 4.1 and 4.2 the general characterization of the equilibrium and the initial results and in section 4.3 the precise predictions in the context of the experiment.

4.1 Equilibria

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

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

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.

[10] In 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.

[11] See the Supplementary Appendix C for details on this application

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 (1) below) and *ii*) Player 1 prefers investing k to playing the degenerate equilibrium (condition 2).

Proposition 1 *A choice of $k \neq k_d$ by Player 1 forms part of a symmetric subgame perfect equilibrium if and only there exists a $\widetilde{\pi}$ such that:*

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

and

$$-c(k) + \frac{\delta}{1-\delta} \alpha \left(\int_0^{\widetilde{\pi}} \pi dF(\pi, k) + \widetilde{\pi} \left(1 - F(\widetilde{\pi})\right) \right) \geq -c(k_d) + \frac{\delta}{1-\delta} \lambda \int_0^{\infty} \pi dF(\pi, k_d) \tag{2}$$

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

To understand the reason that Player 1 may choose to impose an upper bound $\bar{\pi}$, let $\widetilde{\pi}_{\max} = \{\sup \widetilde{\pi} \text{ s.t. (1) holds}\}$. Since the right hand side of (1) is bounded (by $\frac{\delta}{1-\delta} R * E(\pi|k)$), we have $\widetilde{\pi}_{\max} < \infty$. The quantity $\widetilde{\pi}_{\max}$ 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 $\widetilde{\pi}_{\max}$ and to choose $\bar{\pi} = \widetilde{\pi}_{\max}$ in period 0. If not, for realizations $\pi > \widetilde{\pi}_{\max}$, players would be unable to cooperate, low returns would be obtained, and the overall expected return would be lowered.[12]

[12] 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 3.1.3, 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.

The existence of the upper bound $\widetilde{\pi}_{\max}$ 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 in the next section that this may lead to higher equilibrium investments in the absence of legal protections, to relax the investment constraint (1).

4.2 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).[13]

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.*

This result has implications for the types of investments that should be observed in developing countries (application 1, described in section 3). 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 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.

[13] Similar 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.

4.3 Theoretical analysis of the experiment

Proposition 2 can be used to compare the level of investment in environments where legal protection is available to the level in environments where it is not. 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. This special case yields testable predictions that we explore in our experiment.

We now suppose that the returns from investment ($F(\pi, k)$) takes the special form considered in the experiment. In any period, there is either a "failure" worth 0 or a "success" worth $\tilde{\pi}_m$ and the initial investment k determines the likelihood $p(k)$ of obtaining $\tilde{\pi}_m$ in any single period.[14] We use the variable m to parameterize the riskiness of the technology by writing a successful payoff as $\tilde{\pi}_m = \frac{\pi_0}{m}$ and the probability of success $p(k) = mh(k)$. For any investment level k, variations in m induce a mean-preserving spread and have no effect on the expected per period revenue $p(k)\tilde{\pi}_m = h(k)\pi_0$.

With legal protections, the optimal level of investment is independent of m. Formally, let $k^* = \arg\max\left\{-c(k) + \frac{\delta}{1-\delta}p(k)\tilde{\pi}_m\right\} = \arg\max\left\{-c(k) + \frac{\delta}{1-\delta}h(k)\pi_0\right\}$. Then, with legal protections k^* is the optimal investment for all $m \in (0, 1]$.

In the no protection regime, as explained in the previous section, a level of investment k can be sustained if the following two conditions are met:

$$-k + \frac{\delta}{1-\delta}p(k)\frac{1}{2}\pi \geq 0$$

$$\frac{1}{2}\pi + \frac{\delta}{1-\delta}p(k)\frac{1}{2}\pi \geq \pi + 0$$

The first condition guarantees a positive investment and the second guarantees no deviation on the equilibrium path.

As Proposition 2 showed, in the no-protection regime, investment k^* gets harder to sustain as m falls. 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^*.

Defining *strict* equilibrium an equilibrium in which all players strictly prefer following the path to deviating, we obtain the following result:

Proposition 3 *Suppose that for $m = 1$ there is a strict symmetric subgame perfect equilibrium*

[14] Consider, 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.

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.

Consider the special case considered in our experiment.[15] In the legal protection treatments, the optimal choice of a risk-neutral player k^* is an investment level of 1.[16] In the LV treatment, 1 is part of an equilibrium, and so are all the other investment levels. The HV treatment is obtained from the LV treatment by applying a factor $m = 1/2$: the prize is doubled but the probabilities of success for all investment levels, are divided by two. We find that 1 is no longer part of an equilibrium in the *HV* treatment, while all levels above 1 still are.

Examining the incentives of the players (shown in Table 4) following an investment of 1 by player 1 brings out clearly the mechanism developed in the theory. In both the NP-HV and NP-LV treatments, when player 1 invests 1, in the subgame following a successful realization of the investment, each player's continuation payoff is 6.8 if both of them play C for the rest of the game. However, in the LV treatment (where the prize is low) a player's instantaneous gain from deviating to D is only 4, while in the HV treatment it is 8. Cooperation is thus possible only with a low prize.

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. Our main prediction is the following:

Hypothesis 1: An investment of 1 is less likely in the NP-HV treatment than in the NP-LV treatment.

The mechanism is based on the idea that, following an investment of 1, playing C is part of an equilibrium in the *LV* treatment but isn't in the *HV* treatment. This yields the second indirect test of the theory

[15] In the specific case of the experiment, $\underline{m} = 0,35$ (value of m where players are exactly indifferent in a period post investment between cooperating and deviating if the probability of getting the prize is 0.3 in future periods) and $\overline{m} = 0.58$ (same calculation for a probability of 0.5).

[16] Note however that 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. While 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.

Hypothesis 2: Following an investment of 1 by the investor, a play of D by player 2 is more likely in the NP-HV treatment than in the NP-LV treatment.

Hypothesis 2 focuses on the actions of player 2 in the prisoner's dilemma phase following an investment of 1 by player 1. Cooperation or deviation following by player 1 after he invested 1 is difficult to interpret since in the NP-LV investing 1 cannot be part of an equilibrium.

5 Experimental results

5.1 Procedure and summary statistics

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.[17] 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 supergames. The average earnings of players was 17.8 euros.[18] 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.[19] Table 5 in Appendix A reports summary statistics on subjects characteristics both for NP and LP treatments and statistics about the structure of the games for NP treatments, distinguishing between NP-HV and NP-LV. The majority of subjects are male students with low levels of risk aversion. Focusing on NP treatments, subjects play on average 14 supergames lasting 5 rounds each. 19 percent of subjects do not change strategy in different supergames and stick to the initial choice of cooperation or defection and 3 percent of subjects stick to the initial cooperation choice for the whole experiment.

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.[20]

[17]The 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 relies 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.

[18]Subjects did not receive a show up fee.

[19]Self-reported risk attitudes are coded based on a question asking participants to position themselves on a scale between 0 and 10 from more risk averse to more risk loving. Some participants did not fill in the survey which explains that regressions controlling for individual characteristics will be run on fewer observations.

[20]We 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.

5.1.1 Testing the central theoretical prediction

We first test the central prediction of the theory summarized in *Hypothesis 1.* Figure 1, focusing on the bottom panels, clearly shows that the percentage of players investing 1 drops when moving from the NP-LV treatment to the NP-HV treatment, thus graphically validating Hypothesis 1. 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 made between the two LP treatments (Figure 1 top panels), the effect tends to go in the other direction: in the case of legal protection of the investment, an investment of one is more likely in the HV treatments. 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.

Infinitely repeated games in the lab are often characterized by process of learning, either about the game itself, or about the characteristics of the population (see for instance Dal Bo and Frechette (2011)). In Figure 2, we examine the evolution across supergames of the percentage of players investing 1, comparing the NP-HV and NP-LV treatments. While the levels are initially similar, for later supergames, the percentage of players investing 1 becomes significantly higher in the NP-LV treatment.[21]

We test formally Hypothesis 1 controlling for different factors. Table 6 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-LV treatment is significantly higher than in the NP-HV treatment. This is in particular the case for late matches (considered in column (8)), reflecting the potential role of learning.

While the theory makes a clear prediction that an investment of 1 should be significantly less likely in the NP-HV treatments, it does not indicate whether the players should then revert to playing the degenerate equilibrium, or should start investing more. An added value of the experiment is that we can also document these behaviors not described by the theory. Figure 1 clearly shows that both types of transfers occur: players are significantly more likely to invest 0 in the NP-HV treatment compared to NP-LV but also significantly more likely to invest 11. Overall, we find that this leads to a higher average level of investment under the NP-HV treatment than under the NP-LV. We discuss this further in section 5.1.3.

5.1.2 Cooperative behavior

The mechanism we highlight in the theory is based on the fact that an investment of 1 is not sufficient in the NP-HV treatment to sustain cooperation. This intuition is summarized in *Hypothesis 2.*

Before formally testing Hypothesis 2, we first document in Figure 4 the rate at which CC and

[21] Figure 2 shows that this is mostly due to the proportion of those playing 1 increasing in the NP-LV treatment rather than the proportion in NP-HV falling. See Figure 8 in Supplementary Appendix C for details on the different investment choices by treatment over time.

DD are played. The Figure shows that DD outcomes are more likely in the NP-HV treatments, and particularly so in later matches.

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 DD to be the most likely outcome? It may therefore be more natural to focus on the behavior of player 2 following an investment of 1 by the investor, as summarized in Hypothesis 2. The results are presented in Figure 5: player 2 is more likely to choose D in the high-volatility treatments than the low volatility treatments. The results presented in table 7 (behavior of player 2) and 8 (outcome of the game) confirm these graphical results. The effect of the treatment is particularly strong when controlling for individual characteristics, such as whether the player cooperated in the first round of the game or whether he invested in the previous supergame.

Our theory predicts that cooperation is significantly more likely following an investment of 1 in the NP-LV than in the NP-HV since grim trigger is no longer an equilibrium in the NP-HV treatment. Following all other levels of investment, grim trigger is an equilibrium. However, the more player 1 invests, the higher the expected continuation value in equilibrium if CC is played whenever a prize is obtained and thus the higher the incentives to keep cooperating. It is therefore natural to examine how cooperation varies when the investment levels change. Figure 5 examines this question, separating decisions by Player 1 and Player 2. There is a very slight trend for Player 1 in the HV treatment, but not significant.

5.1.3 Average levels of investment

Comparing the level of investment in an environment, such as the one described in our theoretical analysis, with and without legal protection is hard based on real world data for the 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 compare in Figure 6 the average levels of investment across the different treatments. The first thing to notice is that the average level of investment is slightly higher under no protection than under protection, in particular when comparing only the high volatility treatments. This important fact suggests legal protection is not a necessary condition for investment.

The second fact that clearly stands out is that the average level of investment is higher under the NP-HV treatment compared to the NP-LV treatment. In the experiment we thus find that taking a mean-preserving spread of the distribution leads to more investment on average. The theory just predicts that an investment of 1 should become less likely, but does not indicate what the reversal should be. Our experiment shows that players react by both reverting to the degenerate equilibrium for some of them, but also investing more for others.

6 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.[22] 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.

Our model can explain such behavior. On the equilibrium path, Red Hat's clones, rationally choose not to be too aggressive.[23] 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.

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

[23]The 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).

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7 Appendix A

Table 3: Investment options in HV vs LV treatments

	LV	**treatments**	**HV**	**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 4: Profits and deviation incentives in NP treatments

	LV	**treatments**	**HV**	**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 refers to the equilibrium expected profits, in a period post investment where a prize is obtained, under the assumption that (C, C) is played, i.e $\frac{1}{2}\pi + \frac{\delta}{1-\delta}p(k)\frac{1}{2}\pi$. Deviation incentives is the difference between the prize (i.e deviation profits) and the expected profits, i.e $\pi - \left(\frac{1}{2}\pi + \frac{\delta}{1-\delta}p(k)\frac{1}{2}\pi\right)$ A positive value for the deviation incentives means that level of investment cannot be part of an equilibrium.

Table 5: Summary statistics

	(1) NP-LV	(2) NP-HV	(3) LP-LV	(4) LP-HV	(5) LP	(6) NP
N supergames per subject	14.05	16.66				
	(9.30)	(11.90)				
N rounds in match	5.51	5.30				
	(5.66)	(5.70)				
gender	0.32	0.38	0.24	0.49	0.34	0.35
	(0.47)	(0.48)	(0.42)	(0.50)	(0.47)	(0.47)
student	0.64	0.46	0.88	0.31	0.66	0.56
	(0.47)	(0.49)	(0.32)	(0.46)	(0.47)	(0.49)
risk	4.97	5.88	4.59	5.06	4.77	5.39
	(2.20)	(1.95)	(1.96)	(1.69)	(1.87)	(2.13)
Observations	491	456	499	310	809	903

mean coefficients; sd in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Investment decision

	(1) Investment 1	(2) Investment 1	(3) Investment 1	(4) Investment 1	(5) Investment 1	(6) Investment 1	(7) Investment 1
NP-HV	-0.37**	-0.29**	-0.36*	-0.41*	-0.37*	-0.28	-0.43**
	(0.15)	(0.13)	(0.21)	(0.21)	(0.21)	(0.18)	(0.20)
gender		-0.034	0.145	0.142	0.131	0.135	0.274
		(0.228)	(0.216)	(0.216)	(0.209)	(0.232)	(0.225)
student		0.645***	0.631***	0.569**	0.634***	0.650***	0.616**
		(0.247)	(0.222)	(0.238)	(0.223)	(0.222)	(0.242)
risk=3			-0.128	-0.188	-0.117	-0.230	0.053
			(0.424)	(0.374)	(0.421)	(0.400)	(0.627)
risk=4			0.320	0.321	0.321	0.345	0.428
			(0.294)	(0.279)	(0.287)	(0.331)	(0.376)
risk=5			-0.082	-0.143	-0.077	-0.200	0.027
			(0.441)	(0.396)	(0.430)	(0.449)	(0.590)
risk=6			-0.474	-0.514	-0.457	-0.635	-0.210
			(0.558)	(0.520)	(0.547)	(0.646)	(0.691)
risk=7			-0.261	-0.312	-0.257	-0.274	-0.124
			(0.432)	(0.441)	(0.436)	(0.455)	(0.583)
risk=8			0.350	0.293	0.364	0.271	0.483
			(0.531)	(0.512)	(0.529)	(0.544)	(0.645)
risk=9			-1.316	-1.447*	-1.317	-1.467*	-1.162
			(0.815)	(0.875)	(0.806)	(0.770)	(0.953)
risk=10			-0.962***	-0.936***	-0.952***	-0.921***	
			(0.163)	(0.160)	(0.155)	(0.199)	
Supergame				0.014			
				(0.012)			
lengthLastmatch					-0.015*		
					(0.008)		
firstCoop						0.384**	
						(0.159)	
Constant	-0.162**	-0.563***	-0.510*	-0.622**	-0.435	-0.571*	-0.611
	(0.072)	(0.139)	(0.288)	(0.292)	(0.276)	(0.314)	(0.480)
Observations	947	893	893	893	893	893	702

In parentheses, standard errors clustered at session level. In the last column we report results for supergames following the fifth match.
Investment 1 is a dummy variable that is equal to 1 when Player 1 invested 1 token / risk represents the answers to the risk aversion questionnaire / Supergame is a variable measuring the number of supergames played in the past / LengthLast is a variable taking the value of the number of rounds played by player i at t-1 / firstCoop is a dummy equal to one if Player i Cooperated at the first round of the first match.

Table 7: Cooperation by Player 2

	(1) Cooperation P2	(2) Cooperation P2	(3) Cooperation P2	(4) Cooperation P2	(5) Cooperation P2	(6) Cooperation P2	(7) Cooperation P2
NP-HV	-0.44	-0.36	-0.71**	-0.69*	-0.69*	-0.63**	-0.84**
	(0.38)	(0.31)	(0.36)	(0.36)	(0.40)	(0.32)	(0.42)
gender		0.014	-0.041	-0.034	-0.049	0.589	-0.125
		(0.321)	(0.281)	(0.287)	(0.256)	(0.362)	(0.273)
student		-0.445*	-0.274	-0.203	-0.259	0.403	-0.290
		(0.246)	(0.276)	(0.275)	(0.266)	(0.288)	(0.287)
risk=3			0.242	0.243	0.309	-1.162	-0.192
			(0.685)	(0.682)	(0.689)	(0.780)	(0.644)
risk=4			-0.793	-0.829	-0.780	-2.015*	-1.325
			(1.017)	(1.000)	(1.058)	(1.048)	(0.929)
risk=5			1.456**	1.468**	1.371*	-1.201***	1.427**
			(0.689)	(0.695)	(0.717)	(0.274)	(0.645)
risk=6			0.540	0.516	0.530	-1.987***	-0.208
			(0.731)	(0.684)	(0.745)	(0.591)	(0.665)
risk=7			-0.026	-0.053	-0.020	-1.555***	-0.506
			(0.617)	(0.613)	(0.658)	(0.454)	(0.567)
risk=8			-0.201	-0.187	-0.181	-0.912***	-0.614
			(0.753)	(0.774)	(0.773)	(0.223)	(0.727)
risk=9			-0.415	-0.391	-0.372	-1.898***	-0.832*
			(0.495)	(0.494)	(0.533)	(0.449)	(0.486)
Supergame				-0.009			
				(0.006)			
lengthLastmatch					-0.042***		
					(0.013)		
firstCoop						2.144***	
						(0.254)	
Constant	0.169	0.446	0.366	0.459	0.548	-0.201	0.843*
	(0.245)	(0.402)	(0.540)	(0.510)	(0.530)	(0.285)	(0.480)
Observations	183	171	167	167	167	116	152

In parentheses, standard errors clustered at session level / risk represents the answers to the risk aversion questionnaire
Supergame is a variable measuring the number of supergames played in the past
LengthLast is a variable taking the value of the number of rounds played by player i at t-1
firstCoop is a dummy equal to one if Player i Cooperated at the first round of the first match
* $p \leq 0.1$, ** $p \leq 0.05$, *** $p \leq 0.01$

Table 8: Cooperation outcomes

	(1) CC choices	(2) CC choices	(3) CC choices	(4) CC choices	(5) CC choices	(6) CC choices	(7) CC choices	(8) CC choices
NP-HV	-0.68	-0.49	-1.54***	-1.57***	-1.55***	-1.59***	-1.28***	-1.59***
	(0.53)	(0.45)	(0.47)	(0.48)	(0.48)	(0.47)	(0.48)	(0.39)
genderP1		0.045	-0.876*	-0.804*	-0.819*	-0.881*	-0.948***	-0.952**
		(0.265)	(0.468)	(0.421)	(0.460)	(0.475)	(0.302)	(0.472)
studentP1		-0.015	0.094	0.066	0.096	-0.004	-0.047	0.076
		(0.227)	(0.355)	(0.325)	(0.334)	(0.371)	(0.314)	(0.310)
genderP2		0.068	-0.222	-0.259	-0.229	-0.231	-0.231	-0.235
		(0.361)	(0.229)	(0.242)	(0.240)	(0.226)	(0.274)	(0.291)
studentP2		-0.144	0.345	0.384	0.454**	0.314*	0.558**	0.401
		(0.236)	(0.213)	(0.235)	(0.201)	(0.175)	(0.276)	(0.248)
riskP1=3			1.135*	1.302**	1.197**	1.154*	0.886*	1.206*
			(0.580)	(0.591)	(0.552)	(0.605)	(0.538)	(0.628)
riskP1=4			-1.116	-1.020	-1.084	-1.017	-0.874	-1.171
			(0.770)	(0.778)	(0.719)	(0.812)	(0.658)	(0.756)
riskP1=5			2.423**	2.642***	2.513**	2.685**	2.268**	2.480**
			(1.045)	(1.000)	(0.996)	(1.043)	(0.953)	(0.975)
riskP1=6			1.531	1.670*	1.581	1.622	0.965	1.548
			(1.033)	(0.983)	(0.972)	(1.082)	(0.752)	(1.020)
riskP1=7			-0.261	-0.042	-0.109	-0.288	0.103	-0.319
			(0.561)	(0.695)	(0.672)	(0.510)	(0.488)	(0.721)
riskP1=8			0.631	0.759	0.666	0.746	0.694	0.715
			(0.756)	(0.780)	(0.747)	(0.768)	(0.703)	(0.716)
riskP2=3			-0.118	-0.185	-0.145	-0.149	-0.006	-0.241
			(0.470)	(0.361)	(0.394)	(0.493)	(0.540)	(0.563)
riskP2=4			-0.984	-1.066	-1.061	-1.049	-0.691	-0.923
			(1.002)	(0.955)	(0.974)	(1.089)	(1.005)	(0.995)
riskP2=5			1.250*	1.061*	1.155*	1.102	1.312**	1.342*
			(0.672)	(0.584)	(0.604)	(0.683)	(0.569)	(0.765)
riskP2=6			0.497	0.448	0.473	0.635	0.652	0.790
			(0.490)	(0.379)	(0.389)	(0.546)	(0.444)	(0.527)
riskP2=7			-0.603	-0.742	-0.682	-0.749	-0.488	-0.652
			(0.502)	(0.456)	(0.489)	(0.535)	(0.512)	(0.531)
riskP2=8			-0.141	-0.290	-0.207	-0.286	0.017	-0.137
			(0.498)	(0.394)	(0.469)	(0.544)	(0.512)	(0.512)
riskP2=9			-0.529	-0.750**	-0.647*	-0.442	-0.289	-0.728
			(0.342)	(0.359)	(0.372)	(0.300)	(0.354)	(0.754)
riskP2=10			-0.047	-0.148	-0.104	-0.099	-0.088	-0.110
			(0.607)	(0.521)	(0.540)	(0.602)	(0.542)	(0.637)
Supergame				-0.026*	-0.013			
				(0.015)	(0.014)			
Supergame				0.017				
				(0.012)				
lengthLastmatch						-0.085***		
						(0.028)		
firstCoop							0.901***	
							(0.263)	
HadInvested								-0.144
								(0.432)
Constant	-0.311	-0.247	-0.703	-0.578	-0.582	-0.225	-1.154	-0.569
	(0.280)	(0.623)	(0.983)	(0.941)	(0.966)	(1.162)	(1.056)	(1.291)
Observations	183	165	163	163	163	163	163	154

In parentheses, standard errors clustered at session level
LengthLast is a variable taking the value of the number of rounds played by player i at t-1
Supergame is a variable measuring the number of supergames played in the past
CC choices is a variable equal to one when both Players chose to cooperate
firstCoop is a dummy equal to one if Player i Cooperated at the first round of the first match
* $p \leq 0.1$, ** $p \leq 0.05$, *** $p \leq 0.01$

Figure 1

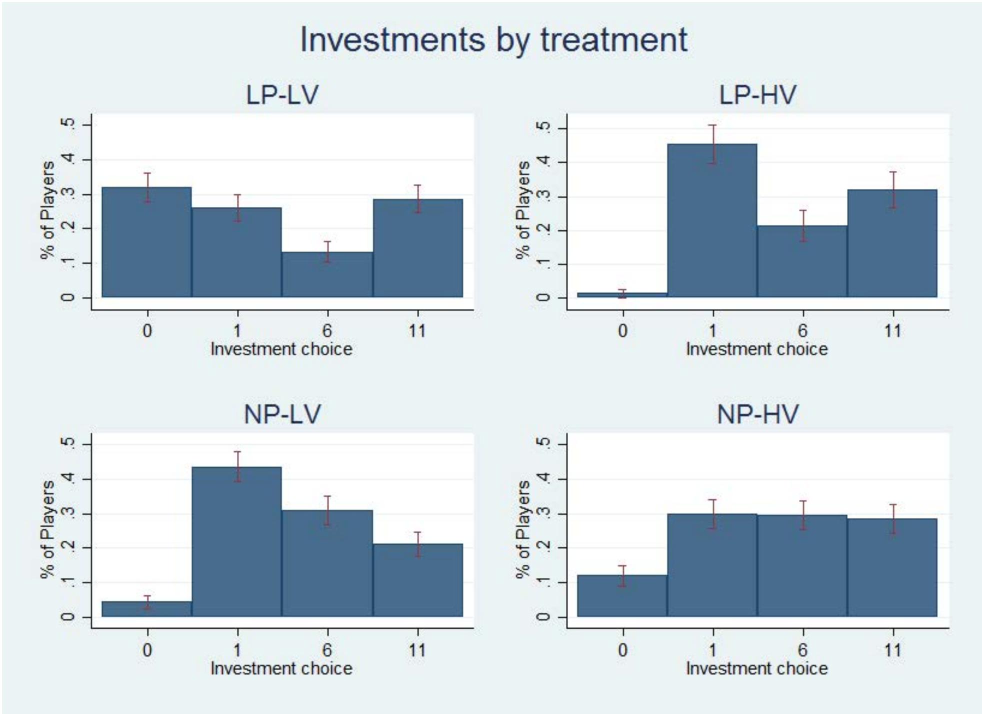


Figure 2

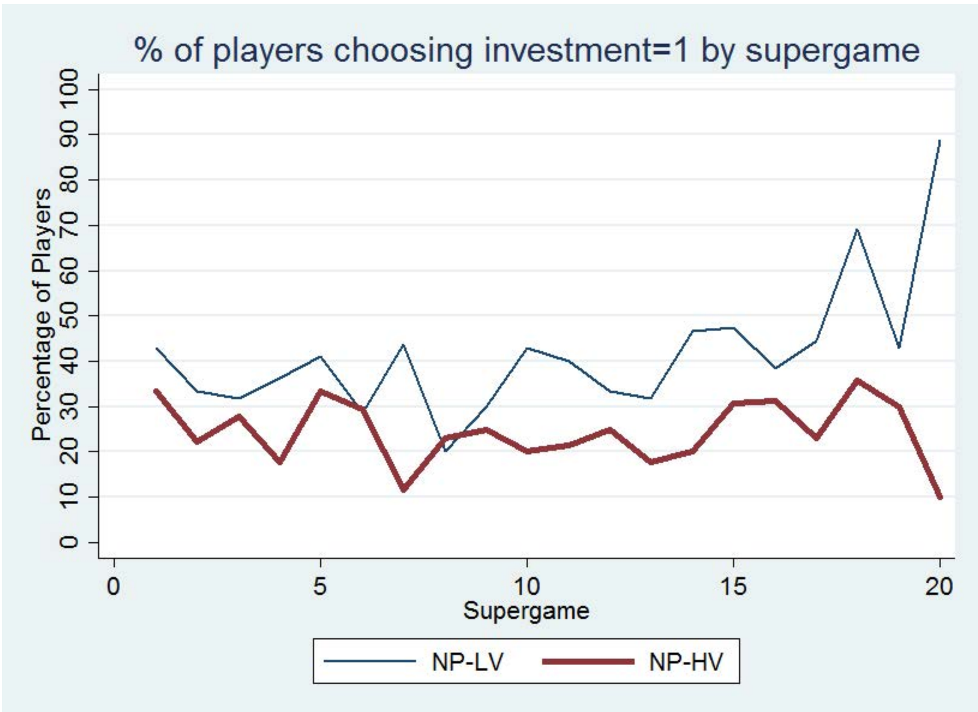


Figure 3

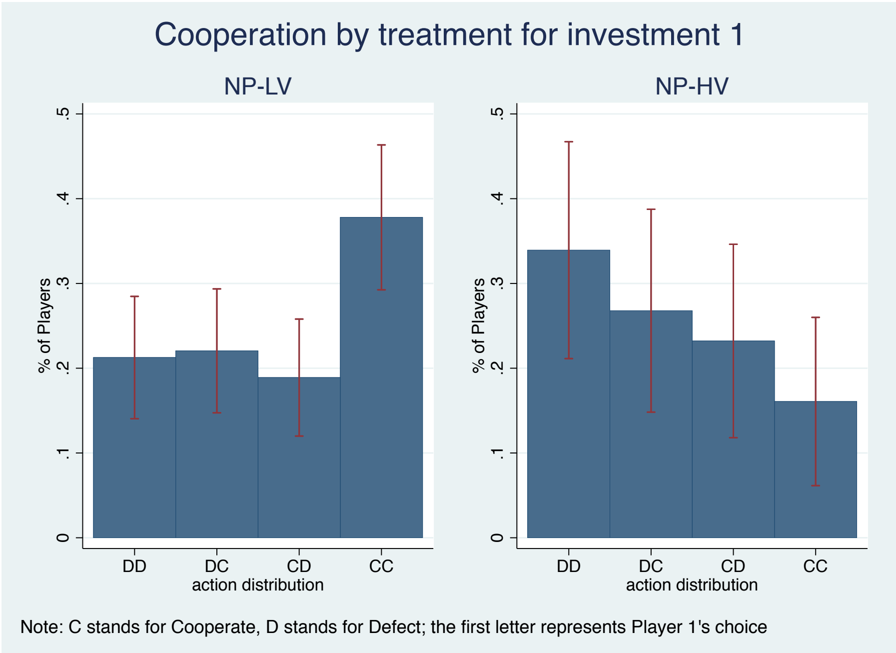


Figure 4

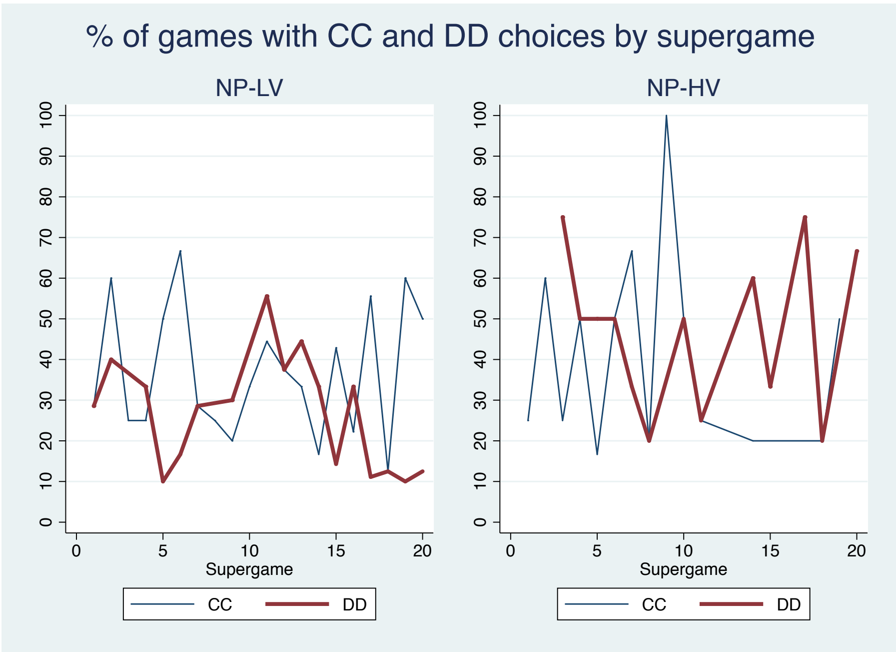


Figure 5

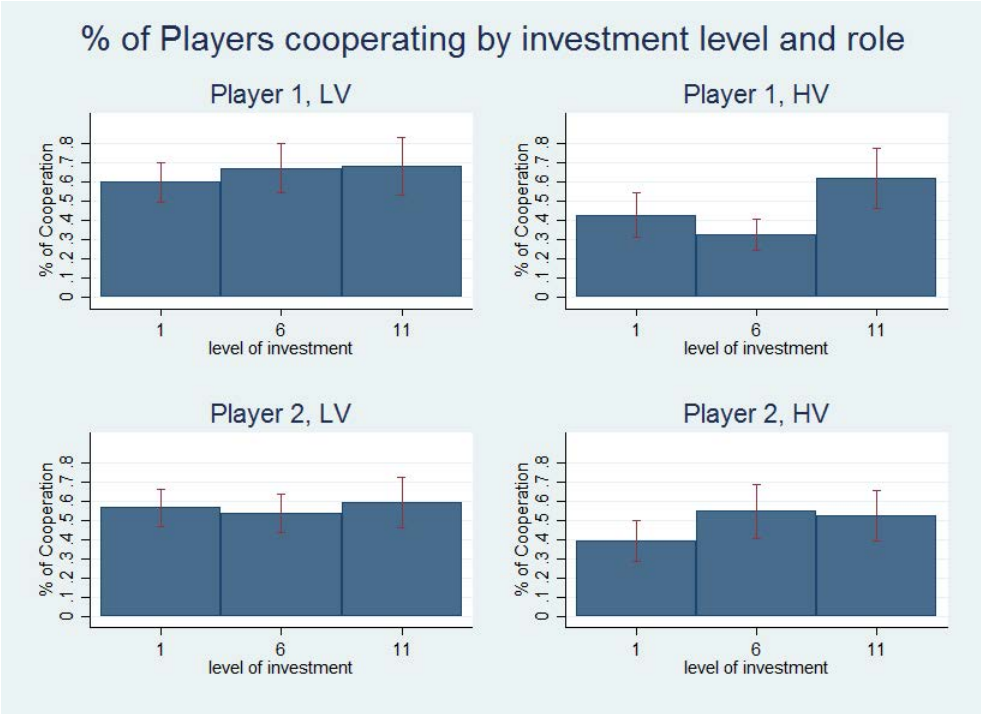
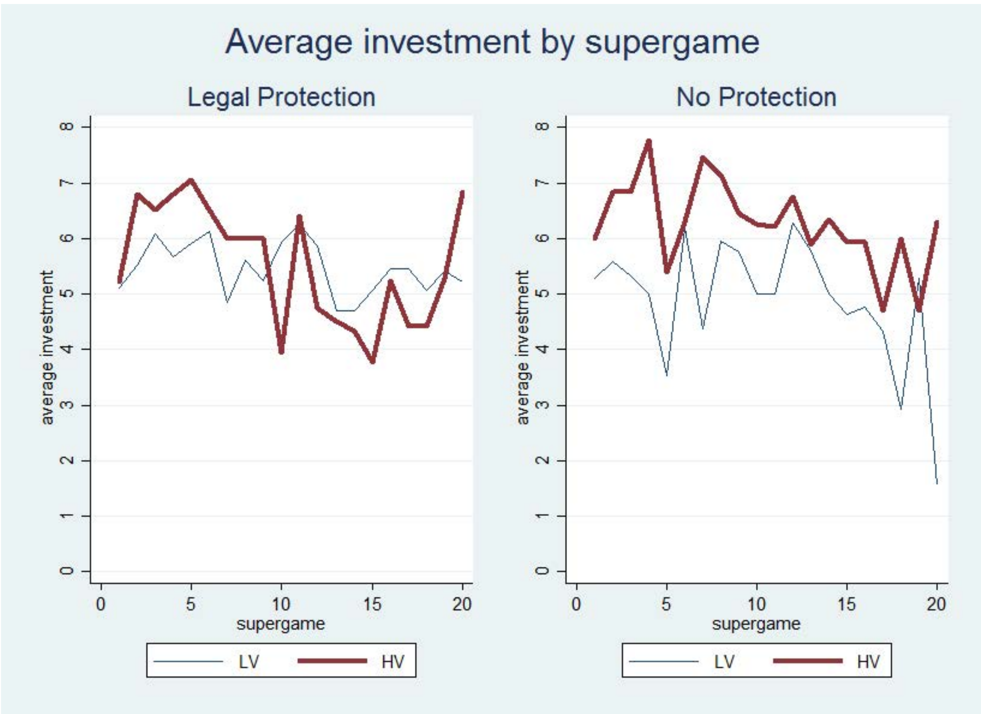


Figure 6



8 Appendix B

Proof of Proposition 1. Suppose there exists a value $\tilde{\pi}$ and an investment k such that conditions (1) and (2) hold and let Player 1 choose $\overline{\pi} = \tilde{\pi}$ in Period 0 along with an investment k. Consider an equilibrium path in which both 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 $\hat{\pi}_t = \min\{\pi_t, \overline{\pi}\}$. Starting in period t, following the path yields a player (for $i = 1$ or o)

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

while deviating yields

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

Both players follow the path if

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

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

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

From condition (2), this expected payoff is larger than the payoff from choosing a different value of k since the other player play D forever in that case. Therefore conditions (1) and (2) guarantee that a subgame perfect equilibrium with investment $k > k_d$ exists.

Conversely, for given k, let $\tilde{\pi}_{\max} = \{\sup\tilde{\pi} \text{ s.t. } 1 \text{ holds}\}$ (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:

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

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

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

and

$$-k + \frac{\delta}{1-\delta}\alpha\left(\int_0^{\widetilde{\pi}} \pi dG\left(\pi, k\right) + \widetilde{\pi}\left(1 - G\left(\widetilde{\pi}\right)\right)\right) \geq -k_d + \frac{\delta}{1-\delta}\lambda\int_0^{\infty} \pi dG\left(\pi, k_d\right)$$

Integrating by parts, we can rewrite these conditions as:

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

and

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

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

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

Hence,

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

and

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

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:

$$\frac{\pi_0}{m} \leq \frac{\delta}{1-\delta} Rmh(k)\frac{\pi_0}{m} \Leftrightarrow \frac{1}{m} \leq \frac{\delta}{1-\delta} Rh(k) \tag{3}$$

and

$$-k+\frac{\delta}{1-\delta}\alpha\pi_0 h(k)\geq -k_d+\frac{\delta}{1-\delta}\lambda\pi_0 h(k_d) \tag{4}$$

Let $\overline{m}$ be defined by:

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

For $m>\overline{m}$, the cooperation constraint (3) is satisfied. Given that k^* is part of an equilibrium for m=1, the investment constraint (4) 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 $m<\overline{m}$, the cooperation constraint (3) 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:

$$-\underline{k}+\frac{\delta}{1-\delta}\alpha\pi_0 h(\underline{k})=-k_d+\frac{\delta}{1-\delta}\lambda\pi_0 h(k_d)$$

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:

$$G(k)=-k+\frac{\delta}{1-\delta}\alpha\pi_0 h(k)-\left(-k_d+\frac{\delta}{1-\delta}\lambda\pi_0 h(k_d)\right)$$

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 $k>\underline{k}$ ■

9 Appendix C: Supplementary Material

9.1 Details on applications

Investment in countries with weak property rights

In the case of investments in countries with weak property rights, we can 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 $\overline{\tau}$ (i.e., expropriate the firm). The game is then the following:[24]

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

Investment in innovation

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 $0\leq\lambda_i<\frac{1}{N+1}$.[25] By setting $\lambda_i=0$, we can think of (D,D) as a reduced form way of modeling a price war down to marginal cost.

9.2 Additional theoretical results

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.[26] The following Proposition shows that, again, this may force Player 1 to invest more than k^*.

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

[25]Thus, if $N=4$, when two firms play D each one earns $\frac{\zeta}{5}$, 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 $\frac{\zeta}{m}$ without affecting our results.

[26]Note that varying R amounts to varying the shares $\alpha,\beta,\gamma,\lambda$.

Proposition 4 *Fix 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 $\overline{R}$ such that in the no-protection regime:*

- *If $R \in [\overline{R}, +\infty]$, there may exist subgame perfect equilibria where Player 1 invests more than, less than, or the same as k^*.*
- *If $R \in [\underline{R}, \overline{R}]$, 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.

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 $\tilde{\pi} \leq \frac{\delta}{1-\delta} R p(k^*) \tilde{\pi}$. Let $\overline{R}$ be defined by $1 = \frac{\delta}{1-\delta} \overline{R} p(k^*)$. Since k^* forms part of a strict equilibrium, $\frac{\bar{\alpha}-\bar{\lambda}}{\beta-\bar{\alpha}} > \bar{R}$ and $-k^* + \frac{\delta}{1-\delta} \bar{\alpha} p(k^*) \tilde{\pi} > -k_d + \frac{\delta}{1-\delta} \bar{\lambda} p(k_d) \tilde{\pi}$. By continuity, there are parameters α, β, γ, and λ for which $R > \overline{R}$ and Player 1 invests more than k^* and parameters for which he invests less. In these equilibria, the other player threatens to play non-cooperatively if Player 1 does not make the "appropriate" investment.

If $R < \overline{R}$, 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 $R < \overline{R}$ and a higher investment forms part of an equilibrium.

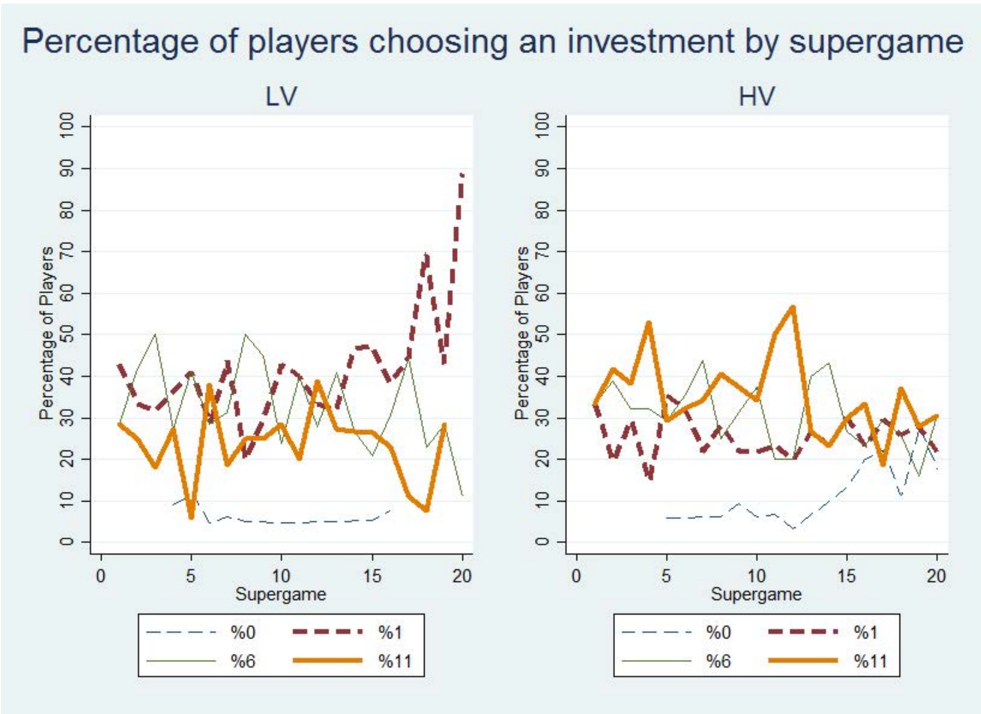
Finally, let $G(k) = -k + \frac{\delta}{1-\delta} p(k) \tilde{\pi}$. Notice that, $G(0) = 0$ and $G(k^*) > 0$. Since $G'' < 0$ and $G\left(\frac{\delta}{1-\delta} \tilde{\pi}\right) < 0$, there exists a $\hat{k} > k^*$ such that $G(\hat{k}) = 0$ and $G(k) < 0$ for all $k > \hat{k}$. Define $\underline{R}$ by $1 = \frac{\delta}{1-\delta} \underline{R} p(\hat{k})$. 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, $-k + \alpha \frac{\delta}{1-\delta} p(k) \tilde{\pi} < G(k) < 0$. Thus, in this region, the only subgame perfect equilibrium involves an investment $k = k_d$. ∎

Table 9: Cooperation by Player 2

	(1) Coop. P2	(2) Coop. P2	(3) Coop. P2
HadInvested	0.34		
	(0.23)		
investment	0.012		
	(0.012)		
investment=6		0.366	0.106
		(0.332)	(0.239)
investment=11		-0.476	-0.458
		(0.519)	(0.588)
HadInvested=1 × investment=1		0.390**	0.453
		(0.166)	(0.482)
HadInvested=1 × investment=6		0.072	0.253
		(0.411)	(0.446)
HadInvested=1 × investment=11		1.007**	0.897
		(0.403)	(0.803)
Supergame			-0.013*
			(0.007)
lengthLastmatch			-0.022***
			(0.008)
Controls	No	No	Yes
Observations	452	452	412

In parentheses, errors clustered at session level / controls include player's gender and student status / HadInvested is a variable taking the value of 1 if player B invested > 0 the last time he played as the investor

Figure 7



Percentage of players choosing an investment by supergame
LV
HV
Percentage of Players
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
Supergame
%0
%1
%6
%11