Abstract

Two main classes of channels are studied as informational sources of financial contagion. One is a fundamental channel that is based on real and financial links between economies, and the second is a social learning channel that arises when agents base their decisions on noisy observations about the actions of agents in foreign markets. Using global games, I present a two country model of financial contagion in which both channels can be operative and I test its predictions experimentally in an effort to distinguish the relative strength of these channels as determinants of subjects’ behavior. While the theory makes clear statements about which channel should be relevant in the different treatments of the experiment, we observe systematic deviations in the way subjects use the information at their disposal. Two main biases arise: a base rate neglect bias, by which subjects underweight their prior, and thus rely less on the fundamental channel, and an overreaction bias where subjects put too much weight on the information derived by the behavior of agents in a foreign market, thus strengthening the social learning channel. These results have important welfare consequences and provide a characterization of the conditions in the economy that can increase or reduce the strength of each of these channels in spreading contagion.

Keywords: contagion, global games, experiments, social learning, behavioral biases
JEL classification: C7, C9, D8, G15
1 Introduction

Financial globalization has given rise to an increase in the number of financial crises that are rapidly transmitted across countries, a phenomenon known as financial contagion (see Schmukler et al, 2006). The crises in Greece and Cyprus and the spread of financial distress in countries like Spain, Italy, or Portugal have brought about some speculation about a latent episode of contagion in the European Union. However, because of the complexity of contagious episodes, such as those occurring after the crises originated in Mexico in 1994-1995, Thailand in 1997 or Russia in 1998, there is no consensus about the specific mechanisms that lead to financial contagion.

Different authors have emphasized different channels for the propagation of crises through contagion. Among the plethora of channels studied in the literature, we can distinguish two main classes: one based on fundamental links and another based on investors’ behavior associated with social learning (see Kaminsky et al, 2003, or Schmukler et al, 2006). Contagion occurs through the fundamental channel when a crisis spreads across countries because of linkages that affect their fundamentals, for example, through trade or financial links. On the other hand, contagion can also occur between countries with weak or no fundamental links that share external characteristics that make investors fear a crisis in one country after observing a crisis in a similar market. Under this view, contagion arises due to social learning, where investors observe the actions of others in foreign markets and act according to beliefs about the apparent similarity between markets, that then become self-fulfilling. This might lead to a crisis in the second country that could have been avoided. In both of these cases speculation is exacerbated by incomplete and asymmetric information among investors, and between investors and governments. However, the sources of the increase in speculation under these two views are very different. Taking a debt crisis contagion as an example, in the first case a country might default because it is unable to honor its debt due to insolvency that is related to the insolvency of another country that has defaulted. In the latter case, a default might occur due to the illiquidity caused by the mass withdrawal of funds based on speculation, after observing agents withdraw their funds in a similar market. Note, that these two channels are not mutually exclusive.

This paper studies theoretically and experimentally the effects and interaction of information related to fundamental links and social learning on the propagation of a crisis through financial contagion. I develop a theoretical model of financial contagion based on global games that is then tested experimentally with the purpose of providing some empirical evidence about these channels under different conditions of the economy. The theoretical model provides the base structure for the experiment and has desirable features, such as the tension between strategic and fundamental uncertainty, while providing enough simplicity to isolate the parameters that determine the strength of each of the channels. My aim is to characterize how information related to fundamentals and social learning affects individual

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1 See Claessens and Forbes (2001) for a compilation of studies that focus on specific channels that could have lead to contagion in the crises of the 1990’s.

2 For example, it might be rational for agents to follow the actions of others in a foreign country as long as the two countries are linked through fundamentals. However, it might also be the case that social learning serves as a channel of contagion in the absence of fundamental links.
behavior, and how this behavior leads to contagion under different economic environments. Therefore, the purpose of the experimental analysis is not just to test a theoretical model, but to understand the behavioral mechanisms behind the channels of contagion. To my knowledge, this is the first paper that studies a global games model of financial contagion experimentally.

As pointed out by Goldstein (2012), differentiating between these channels is crucial for policy analysis. However, there is no conclusive empirical evidence on the matter. Although a large empirical literature has established a strong link between contagious episodes and fundamentals (see, for example, Caramazza et al, 2004, and Kaminsky et al, 2004), not all episodes of contagion can be explained by fundamental links. Many studies focus on the role of panic due to social learning in generating contagion, but the social learning channel is difficult to test empirically because it depends crucially on the information sets of agents, which are largely unobservable.3 The laboratory is a useful alternative in this case because it provides a natural environment to study the reaction of agents to different types of information, while controlling the strength of fundamental links and the accuracy of the information related to social learning. Clearly, an experimental session cannot recreate exactly the same situation that investors face in financial markets. However, the tensions and trade-offs are qualitatively mirrored so that we can interpret the behavior of experimental subjects as a qualitative guide of the type of behavior that financial market participants might exhibit.

The model of financial contagion used in this paper has global games as a building block. Global games are coordination games of incomplete information where agents do not know the underlying state of the economy, which determines their payoffs. Instead, they receive noisy private signals about it and have to make inferences about the realization of the state and about the likely actions of others in order to make decisions. This perturbation in the information structure, first introduced by Carlsson and van Damme (1993), leads to a very rich architecture of higher order beliefs and ultimately selects a unique equilibrium in threshold strategies. This feature of uniqueness contrasts with earlier analysis of coordination games which predicted multiple equilibria, and it makes global games very suitable for policy analysis by focusing only on one possible outcome.4 The use of global games to model financial contagion was initially studied by Dasgupta (2004) and Goldstein and Pauzner (2004), who focus on specific mechanisms of contagion (capital connections of banks in the former, investors’ wealth in the latter) to demonstrate that contagion can be an equilibrium outcome in a global game. Therefore, we can think of these papers as setting the theoretical ground to study new questions related to financial contagion with the use of global games.

In this paper I apply the techniques of global games to study how agents incorporate the information relates to two channels of financial contagion in a model with two economies

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3Some studies look for evidence for the social learning channel of contagion. Kaminsky and Schmukler (1999), for example, study the type of news that triggered stock price fluctuations in the Asian markets in 1997-1998. They suggest that herding behavior was responsible for the changes that cannot be explained by any apparent substantial news. This type of inference, however, does not provide conclusive evidence for the social learning channel.

whose fundamentals are correlated (e.g. countries in the European Union) and who are both vulnerable to runs on the funds used to finance their debt. The speculative run in each country is modeled as a global game where investors in each country receive noisy private signals about the state of the economy and have to decide whether to withdraw their funds or to roll over their loans until maturity. It is a sequential model. In period one agents in the first country make their decisions based only on their prior information and on private signals about the state of the economy. In the second period, agents in the second country know the level of correlation between the two countries (fundamental link), they receive a noisy signal about the proportion of agents that withdraw their funds in the first country (social learning link) and they also hold a private signal about the fundamentals in their own country.

Using global games as the workhorse for this model has two main benefits. First, it preserves the fundamental and strategic forces inherent in the unraveling of the speculative episode in each country. Second, it provides a simple way to keep track and vary experimentally the strength of each of the two channels of contagion with the use of only two parameters: the correlation between fundamentals and the precision of the signal about the behavior of agents in the first country.

I first set up the theoretical model with a continuum of agents to understand the main forces and tensions of the model in terms of the channels of contagion. Then I present the discretized model that is implemented experimentally. While keeping the main tensions of the model, I discretize not only the number of players, but also the state space and the signal spaces in order to make the environment easier to understand for subjects. The results of the theoretical model with a continuum of agents illustrate the importance of prior beliefs in determining the direction of comparative statics with respect to the parameters that measure the strength of these two channels. Therefore, I vary the strength of each of the channels and the induced prior to design ten experimental treatments that characterize ten very different environments in the economy in terms of the usefulness of the information related to each of the two channels.

The experimental results revolve around two main hypotheses. The first one relates to how subjects use the information available to them. I first study whether they identify the signals that are informative for their decision or not. Identifying the informative signals illustrates the importance given by subjects to each of the channels of contagion. As described above, agents in the second country have access to three different sources of information, or signals, that, depending on the conditions of the economy, need to be incorporated into their posterior beliefs in order to choose the action that maximizes their expected utility. These signals are the prior distribution about the state in the first country, where the crisis is originated, the public signal about the behavior of agents in the first country, and the private signal about the realized state in the second country. Since the correlation of states determines the strength of the fundamental channel of contagion, agents should take into consideration the prior distribution about the state in the first country (the fundamental channel should be active) only if the states are correlated. On the other hand, subjects in the experiment should take into account the signal about the behavior of agents in the first country (the social learning channel should be active) only if this signal is informative. We say that this signal is informative when it is correlated to the true behavior of agents in the
first country and the states between the two countries are correlated.

The experimental results show two systematic biases that are closely related to the channels of contagion. The first one is a base rate neglect bias, by which subjects underweight the information coming from the prior in cases where the correlation of states is high. This weakens the fundamental channel in the cases where it should have a strong effect. On the other hand, we observe an overreaction bias where subjects systematically take into account the signal about the behavior of agents in the first country, even in cases where this signal is uninformative. This signal can be uninformative either because it is not correlated to the true behavior of agents in the first country or because the fundamentals are not correlated. In other words, we observe a bias that puts too much weight on the social learning channel of contagion.

The second main hypothesis relates to welfare. Due to the two biases found in the data, we see higher frequencies of withdrawals than those prescribed by equilibrium in all but two treatments. As a consequence of such departures, there are significant losses in welfare with respect to equilibrium actions. However, in the two treatments with lower frequencies of withdrawals than those prescribed by equilibrium, we observe significant welfare gains. To explain these results, I focus on the social learning channel of contagion to study the cost, in terms of foregone payoffs, of following others. I study the instances where subjects follow the actions taken by others when the theory prescribes them to take the opposite action, for the set of signals observed. I find that in the treatments where higher frequencies of withdrawals are observed, there is a significant amount of instances where subjects choose to withdraw after observing agents in the first country withdraw, even in the cases where these signals are uninformative. This explains the higher frequencies of withdrawals and lower realized payoffs and it serves as a clear illustration of how overreaction to the social learning channel can lead to contagious panics. However, in the two treatments where we observe significantly lower frequencies of withdrawals, we see a positive effect of the social learning channel of contagion. In these cases not only do subjects not follow withdrawals, but they choose to roll over after observing a signal of agents rolling over in the first country, even if equilibrium prescribes withdrawals. These cases provide evidence for positive contagion where subjects show confidence in the market after observing a signal of agents in a foreign country showing confidence in their own market (contagious confidence). This departure from equilibrium leads to welfare gains as a consequence of more successful coordination.

I then classify subjects according to the type of strategies they use. I compare the mean realized payoffs of those subjects that act according to equilibrium to the payoffs of those who do not, to analyze, given the distribution of types in the sample, how robust is the finding that equilibrium play leads to higher payoffs in most treatments. The results show that in half of the treatments those subjects who play according to equilibrium receive significantly higher mean payoffs than those who do not.

The paper is structured as follows. Section 2 presents the theoretical global games model of financial contagion. I first set up the model with a continuum of agents and discuss the main implications in terms of comparative statics, and then I present the discrete model that is implemented in the laboratory. Section 3 presents the experimental design and the set of parameters used in the experiment. The experimental results are presented in section 5. The full solution and characterization of the model with a continuum of agents is in an online appendix.
4. Section 5 provides a discussion of the results and relates the findings of the paper to the existing literature. Finally, section 6 concludes.

2 Theoretical model

In this section I first introduce the model with a continuum of agents in each country and discuss the main implications from such model in terms of the two channels of contagion. The full characterization of the model is contained in an online appendix.\(^6\) Then I present the discrete model that is implemented experimentally and discuss the expected predictions for the experiment.

There are two countries in the economy, Country 1 and Country 2, and a set of agents in each country that only participate in that specific country. There are two periods and agents related to country \(n = 1, 2\) are active only in period \(n\). For simplicity, I assume that countries become active in the order of their nummaraire.

Both countries use standard debt contracts to finance their debt. These contracts specify an interim stage where agents can review their investment and decide whether to roll over their loan to maturity or to withdraw their funds prematurely. Creditors from country \(n\) have funds invested in country \(n\). Even if the country is solvent, creditors might want to withdraw their funds at the interim stage if they fear that the country may default and not repay its debt, or if they fear that other creditors might withdraw. These fears are self-fulfilling since countries are more likely to default if more creditors withdraw at the same time.

Each country is potentially fragile to default. The state of fundamentals in each country is determined by a random variable \(\theta_n \in \mathbb{R}, n = 1, 2\), that is not known to creditors and determines the level of liquidity in Country \(n\).

The two countries are linked through fundamentals, so \(\theta_1\) and \(\theta_2\) are correlated. A high level of fundamental co-movement between these economies would lead poor fundamentals in one country to imply bad states in the other one, which would increase the probability of a default in the second country, irrespective of the information available to creditors in the second country about the behavior of creditors in the first country.

In each country, domestic creditors buy securities to finance the country’s government debt. The setup in each individual country follows closely the setup of Morris and Shin (2004). The financing is undertaken via a standard debt contract that specifies two different face values, depending on the time of liquidation.\(^7\) The face value of repayment at maturity is \(\gamma_n\) and each creditor who rolls over her loan receives this amount if the country stays solvent. If the country defaults, then creditors who roll over their investment get zero. At an interim stage, creditors have the opportunity to review their investment. If they choose to withdraw their funds prematurely they get the lower face value of early withdrawal \(\lambda_n \in (0, \gamma_n)\).

Whether Country \(n\) honors its debt at maturity or defaults depends on two factors: the underlying state of the economy, \(\theta_n\), and the proportion of agents that withdraw, \(l_n\).

\(^6\)See http://econweb.ucsd.edu/~itrevino/pdfs/continuum_model.pdf.

\(^7\)Two different face values for short and long term debt are also studied in Szkup (2013). However, in that model there is no possibility for contagion and the face values are endogenously determined.
outcome for Country $n$ at maturity will be determined by comparing the realization of the state to the proportion of withdrawing creditors.

The payoff of a creditor in Country $n$ is given by:

<table>
<thead>
<tr>
<th>Solvency at maturity</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll over loan</td>
<td>$\gamma_n$</td>
</tr>
<tr>
<td>Withdraw</td>
<td>$\lambda_n$</td>
</tr>
</tbody>
</table>

If agents knew $\theta_n$ then we could distinguish three regions for the fundamentals such that: If $\theta_n \geq \bar{\theta}_n$, agents would find it optimal to roll over their debt, irrespective of the actions of others (in this case, rolling over always yields the high face value $\gamma_n > \lambda_n$). If $\theta_n < \bar{\theta}_n$, it is optimal to withdraw the funds at the interim stage (in this case the country always defaults and rolling over the funds would lead to a payoff of $0 < \lambda_n$). For $\theta_n \in [\underline{\theta}_n, \bar{\theta}_n)$ there is a coordination problem where the optimal action depends on the beliefs about the state $\theta_n$ and about the actions of the other creditors. However, in this model agents do not observe $\theta_n$ directly, but receive noisy private and public signals about it.

I first setup the model with a continuum of agents in each country and discuss the main implications in terms of comparative statics with respect to the parameters that determine the strength of the two channels of contagion. In this subsection I also assume continuous probability distributions for signals and states. This continuity is assumed in order to have a more complete characterization of the equilibrium of the model and of comparative statics. However, since the purpose of the paper is to test the predictions of the model experimentally, a model with a discrete number of agents is required to establish the theoretical predictions for the experiment. Moreover, this is a fairly complex model, so further discretization of the state and signal spaces is performed in order to make the model more accessible for subjects in the experiment. After presenting the model with a continuum of agents I present the discrete model that is implemented in the laboratory.

### 2.1 Model with a continuum of agents in each country

There is a continuum of agents (creditors) in each country indexed by $i_n \in [0, 1]$, $n = 1, 2$. For this continuum model, I assume that the face value of repayment at maturity is $\gamma_1 = \gamma_2 = 1$, so that each creditor who rolls over her loan receives this amount if the country stays solvent. Whether Country $n$ honors its debt at maturity or defaults is determined by comparing the realization of the state of fundamentals, $\theta_n$, to the proportion of withdrawing creditors, $l_n$, in the following way:

$$
\text{Country } n = \begin{cases} 
\text{Stays solvent if } l_n \leq \theta_n \\
\text{Defaults } \text{if } l_n > \theta_n
\end{cases}
$$

In this sense, $\theta_n$ can be thought of as fundamentals that reflect the ability of the government to meet short-term claims from creditors, or an index of liquidity. Given this characterization, we get that $\theta_1 = \theta_2 = 0$, and $\bar{\theta}_1 = \bar{\theta}_2 = 1$, so that if agents had complete information about the fundamental $\theta_n$ they would roll over their loan if $\theta_n \geq 1$, since rolling over always yields the high face value of $1 > \lambda_n$. If $\theta_n < 0$, creditors would withdraw the funds at the
interim stage, and the coordination region would be for values of the fundamental \( \theta_n \in [0, 1) \).

To model the fundamental link, I assume that the fundamentals in Country 1 are drawn from a normal distribution with mean \( \mu_\theta \) and precision \( \tau_\theta_1 \), i.e. \( \theta_1 \sim N(\mu_\theta, \tau_\theta_1^{-1}) \). Since events in Country 2 come after events in Country 1 have occurred, fundamentals in Country 2 depend on the realization of \( \theta_1 \) by setting the realization of \( \theta_1 \) to be the mean of the distribution from which \( \theta_2 \) is drawn, i.e. \( \theta_2|\theta_1 \sim N(\theta_1, \tau_\theta_2^{-1}) \). This information is common knowledge to all agents in both countries. The parameter \( \tau_\theta_2 \) illustrates the link between fundamentals. Even if it is not strictly a measure of correlation, it has the same interpretation since an increase in \( \tau_\theta_2 \) increases the probability that the realization of \( \theta_2 \) is closer to \( \theta_1 \).

Since agents’ payoffs do not depend directly on the actions that agents in the other country take (before or after), there are no strategic considerations across periods. Therefore the problem is simplified to a series of two static global games where the outcome in the first game affects the outcome in the second one. I solve the two subgames separately and then study the effects that the outcome in Country 1 has on the outcome in Country 2.

Besides holding prior beliefs about \( \theta_1 \), agents in Country 1 also observe noisy private signals about their payoff-relevant state, \( \theta_1 \), given by

\[
x_1^i \sim N(\theta_1, \tau_1^{-1})
\]

where \( x_1^i \) are iid across \( i \in [0, 1] \).

Notice that the game in Country 1 corresponds to a standard static global game, so a unique equilibrium in monotone strategies is guaranteed as long as private signals are precise enough with respect to the prior (or \( \frac{\sqrt{\tau_1}}{\tau_\theta_1} > \frac{1}{\sqrt{2\pi}} \), see Morris and Shin, 2003, Hellwig, 2002, or Morris and Shin, 2004, for details). This unique equilibrium is characterized by a pair of thresholds \( \{\theta_1^*, x_1^*\} \) such that creditors in Country 1 withdraw their funds if \( x_1^i < x_1^* \), and they roll over if the observe a private signal larger than this threshold, i.e. if \( x_1^i \geq x_1^* \). Likewise, Country 1 defaults if the state is low, \( \theta_1 < \theta_1^* \), and it stays solvent and honors its debt if the realization of the state is sufficiently high, \( \theta_1 \geq \theta_1^* \). The thresholds \( \{\theta_1^*, x_1^*\} \) depend on the parameters of the model in Country 1.

For Country 2, the information structure is more complex, but the equilibrium follows the same logic as the equilibrium for Country 1. Just as in Country 1, agents in Country 2 observe private signals about the state in their own country, \( \theta_2 \), given by \( x_2^i \sim N(\theta_2, \tau_2^{-1}) \), where \( x_2^i \) are iid. In addition, agents in Country 2 observe a public signal about the proportion of agents in Country 1 that withdraw their money, which is given by

\[
y|\theta_1 \sim N(\Phi^{-1}(l_1), \eta^{-1})
\]

where \( l_1 = \Pr(x_1^i < x_1^*) = \Phi\left(\frac{x_1^* - \theta_1}{\tau_1^{-1/2}}\right) \) is the proportion of creditors in Country 1 that withdraw their funds.\(^8\) Notice that since \( y \sim N\left(\frac{x_1^* - \theta_1}{\tau_1^{-1/2}}, \eta^{-1}\right) \), \( y \) can be reinterpreted as a

\(^8\)Notice that this transformation assumes monotonic strategies from the part of agents in Country 1. Therefore, I restrict attention to this type of strategies. The transformation facilitates the analysis and follows Dasgupta (2007).
public signal about $\theta_1$. Agents in Country 2 do not observe the realization of $\theta_1$, but they know the setup of the game, so their prior belief about $\theta_1$ is the same as that of agents in Country 1, $\theta_1 \sim N(\mu_\theta, \tau_{\theta_1}^{-1})$. Therefore, agents in Country 2 hold a posterior about $\theta_1$, after observing this signal about the behavior of agents in Country 1, which determines the beliefs of agents in Country 2 about the distribution from which $\theta_2$ is drawn, since $\theta_2|\theta_1 \sim N(\theta_1, \tau_{\theta_2}^{-1})$.

Taking this into consideration, once agents in Country 2 observe their private signals about $\theta_2$, $x_2^i \sim N(\theta_2, \tau_2^{-1})$, they form posterior beliefs about $\theta_2$. As in Country 1, there will be a unique equilibrium characterized by thresholds $\{\theta_2^*, x_2^*\}$ such that agents in Country 2 withdraw their funds if they observe a signal $x_2^i < x_2^*$, and they rollover otherwise, and Country 2 defaults if the state is low, $\theta_2 < \theta_2^*$, and it stays solvent if $\theta_2 \geq \theta_2^*$. The thresholds $\{\theta_2^*, x_2^*\}$ depend crucially on the parameters of the model in Country 1 and Country 2. A sufficient condition for a unique equilibrium in Country 2 is that private signals are informative enough with respect to public information, or $\frac{\sqrt{\tau_2}}{(\tau_{\theta_2} + \tau_{\theta_1} + \eta)^{-1}} > \frac{1}{\sqrt{2\pi}}$.

Notice that in this setup the outcome in Country 1 affects the beliefs of agents in Country 2 through two channels. One is through the signal about the proportion of agents that withdraw their funds in Country 1, $y$, which implies that, as agents observe a signal about a higher proportion of agents that withdraw in Country 1, agents believe that fundamentals in Country 2 are weaker because the states are correlated. This signal incorporates a component of social learning that is not present in the standard model of global games. Moreover, the precision of this signal, $\eta$, plays an important role in determining the extent to which agents in Country 2 should take it into account when updating their beliefs. We can think of this precision $\eta$ as reflecting the accuracy (or quality) of information transmitted between Countries 1 and 2. Therefore, $y$ and $\eta$ represent the social learning channel that, depending on the conditions in the economy, might exacerbate or dampen the beliefs that agents in Country 2 hold about the probability of default in Country 2, arising from the observation of the actions of creditors in Country 1. The parameter that ultimately determines how relevant it is for agents in Country 2 to pay attention to the information related to Country 1 (the prior about $\theta_1$ and the signal about the behavior of agents in Country 1, $y$) is the level of correlation between fundamentals in the two countries, $\tau_{\theta_2}$. This parameter measures purely a fundamental link between countries. Notice that these two channels are informational channels, i.e. both fundamentals and social learning lead to contagion through the information that is revealed to agents.

These two channels of contagion are related - albeit in different ways - to public information held by agents in Country 2. The comparative statics with respect to the fundamental channel characterize changes in the probability of default in Country 2 due to a change in the strength of the correlation between fundamentals, captured by $\tau_{\theta_2}$. The comparative statics with respect to the social learning channel illustrate how the probability of default in Country 2 is affected when agents in Country 2 observe a signal about a higher proportion of agents that withdraw their funds in Country 1 ($y$), and by changes in the precision of this signal ($\eta$). I focus on the effects on the probability of default in Country 2, measured by
changes in $\theta_2^*$, assuming that the conditions for uniqueness of equilibrium hold.\footnote{In a similar setup to the present paper, but where contagion is not a possibility and the analysis is equivalent to that of Country 1, Morris and Shin (2004) show that $\mu_\theta$ has important effects on the probability of default in Country 1. In particular, they show that $\theta_1^*$ is decreasing in the mean of the prior, $\mu_\theta$. This means that a country is able to stay solvent for a wider range of fundamentals (lower $\theta_1^*$) when creditors hold an optimistic prior about the state of the economy (higher $\mu_\theta$).} \footnote{In the online appendix that fully characterizes the model with a continuum of agents I present also comparative statics with respect to other parameters of the model that affect the probability of default of each specific country: the precision of private signals, $\tau_n$, the mean of the prior in Country 1, $\mu_\theta$, the precision of the prior for Country 1, $\tau_{\theta_1}$, and the payo$\bar{f}$ of early withdrawal, $\lambda_n$, for $n = 1, 2$.}

The main takeaway from performing comparative statics in the model with a continuum of agents and continuous distributions is that prior beliefs crucially determine how changes in the strength of the two channels of contagion affect the probability of default in Country 2.

The comparative statics results for the fundamental channel of contagion state that (1) if the probability of default in Country 2 is low and agents have an optimistic prior about the state of the economy, then a higher correlation between Country 1 and Country 2 will further decrease the probability of default in Country 2, and (2) if the probability of default in Country 2 is high and agents have a pessimistic prior about the state of the economy, then a higher correlation between Country 1 and Country 2 will increase the probability of default in Country 2.

This result has a very intuitive interpretation. When agents have an optimistic prior about fundamentals in Country 2, they are optimistic about the realization of fundamentals in Country 1. Therefore, when agents in Country 2 hold an optimistic prior about the state in Country 2, a higher correlation between fundamentals, characterized by a higher $\tau_{\theta_2}$, implies that agents in Country 2 assign a higher weight to these optimistic beliefs and this further decreases the probability of default in Country 2. This illustrates the positive effects of fundamental links in contagion. On the other hand, agents have a pessimistic prior about the state in Country 2 when they believe that the realized state in Country 1 was not good, so in this case a higher correlation between fundamentals in both countries will lead them to assign a higher weight to these pessimistic beliefs, which leads to an increase in the probability of default in Country 2. This illustrates the negative effects of increased fundamental links in the propagation of crises through contagion.

To analyze the social learning channel of contagion we look at the effect that the signal about the proportion of agents that withdraw their funds in Country 1, $y$, and its precision, $\eta$, have on the probability of default in Country 2. In particular, a signal of a higher magnitude about the proportion of agents that withdraw their funds in Country 1, $y$, increases the probability of default in Country 2. This result is not surprising, and could be thought of as a first order effect of the social learning channel of contagion. This effects is stronger as the precision of $y$, measured by $\eta$, increases, for most parameter values.

To analyze the other path of the social learning channel of contagion, i.e. the effect of an increase in the precision of the social earning signal, $\eta$, we need to decompose the notion of optimistic (pessimistic) prior beliefs about the state of Country 2. On the one hand, $\eta$, just like $\tau_{\theta_2}$, is a component of the precision of the posterior or expected distribution of $\theta_2$. Therefore, just like $\tau_{\theta_2}$, the effect arising from changes in $\eta$ on the probability of
default will depend on whether beliefs about $\theta_2$ are optimistic or pessimistic. However, the total effect of changes in $\eta$ on $\theta_2^*$ is more complex than that of $\tau_{\theta_2}$, since a change in $\eta$ also affects the expected mean of the distribution of $\theta_2$, which determines whether beliefs are optimistic or pessimistic. This means that there are two effects arising from an increase in $\eta$ that might go in different directions. The first effect makes agents put more weight on the mean of the prior by increasing the precision of the composed public signal and is called a “coordination effect”, since it enhances coordination by aligning posterior beliefs across agents (this is the effect that is also common to the fundamental link through $\tau_{\theta_2}$). I call the second an “information effect” since it changes the level of the expected mean of the distribution of $\theta_2$, thus affecting the type of beliefs that agents hold. Therefore, an increase in $\eta$ might actually change prior beliefs about $\theta_2$ by changing whether agents are ex-ante optimistic or pessimistic, and depending on the outcome on these beliefs, we would have “new” prior beliefs about $\theta_2$ that will determine the direction of the coordination effect. Numerical results indicate that the relative strength of these two effects depends on the mean of the prior about $\theta_1$ ($\mu_{\theta}$), and on the realization of the social learning signal ($y$).

The above model of financial contagion with a continuum of agents illustrates the main tensions that arise when analyzing the two channels of contagion. The model characterizes this relationship in a parsimonious way by allowing us to isolate these two effects with variations over two different parameters: the correlation between fundamentals and the precision of the signal that agents in Country 2 observe about the behavior of agents in Country 1. The main takeaway of this analysis is that ex-ante or prior beliefs matter in a non-trivial manner as determinants of the direction in which the probability of default in Country 2 changes as we vary the strength of each of the two channels of contagion.

### 2.2 Discrete model

This subsection presents a discrete version of the model that is implemented experimentally. This simplified model has a discrete number of agents and discrete state and signal spaces to make model more accessible for the experimental subjects.

In each Country $n = 1, 2$, there are 2 players. The state $\theta_n$ can be either low, medium, or high, $\theta_n \in \{L_n, M_n, H_n\}$. Just as in the continuous model, in each country $n = 1, 2$ agents make a binary choice $a_n^i \in \{0, 1\} = \{\text{withdraw}, \text{roll over}\}$. To keep the structure of a global game, I assume that when the state is high ($\theta_n = H_n$) the country always stays solvent (rolling over is a dominant strategy), when the state is low ($\theta_n = L_n$) the country always defaults (withdrawal is a dominant strategy), and when the state is medium ($\theta_n = M_n$) the country stays solvent only if both agents coordinate on rolling over. This effectively means that for each possible realization of the state in Country $n = 1, 2$, agents would face one of the matrices of payoffs from table 1.

<table>
<thead>
<tr>
<th>$\theta_n = L_n$</th>
<th>rollover</th>
<th>withdraw</th>
<th>$\theta_n = M_n$</th>
<th>rollover</th>
<th>withdraw</th>
<th>$\theta_n = H_n$</th>
<th>rollover</th>
<th>withdraw</th>
</tr>
</thead>
<tbody>
<tr>
<td>rollover</td>
<td>0, 0</td>
<td>0, $\lambda_n$</td>
<td>rollover</td>
<td>$\gamma_n, \gamma_n$</td>
<td>0, $\lambda_n$</td>
<td>rollover</td>
<td>$\gamma_n, \gamma_n$</td>
<td>$\gamma_n, \lambda_n$</td>
</tr>
<tr>
<td>withdraw</td>
<td>$\lambda_n, 0$</td>
<td>$\lambda_n, \lambda_n$</td>
<td>withdraw</td>
<td>$\lambda_n, 0$</td>
<td>$\lambda_n, \lambda_n$</td>
<td>withdraw</td>
<td>$\lambda_n, \gamma_n$</td>
<td>$\lambda_n, \lambda_n$</td>
</tr>
</tbody>
</table>

Table 1: Payoffs in the discrete model, Countries 1 and 2.
Recall from above that $\lambda_n \in (0, \gamma_n)$, for $n = 1, 2$. Below I describe the discretization of the signal structure first and discuss the features of equilibrium for the discrete model for Country 1, and then for Country 2. Notice that by discretizing the model in this way we lose some convenient features of global games with continuous distributions, like the possibility to ensure uniqueness of equilibrium for a wide range of parameters. For this reason we cannot generalize results in this setup. However, the parameters in the different treatments of the experiment are chosen to ensure a unique equilibrium.

2.2.1 Country 1

The prior (unconditional) distribution for $\theta_1$ is characterized by probabilities $p$ and $q$: $\Pr(L_1) = p$, $\Pr(M_1) = q$, and $\Pr(H_1) = 1 - p - q$. The prior distribution of $\theta_1$ is also known to agents in Country 2.

Private signals for agents in Country 1 can be either low, medium, or high, $x_1^i \in \{l_1, m_1, h_1\}$, and the conditional distribution of these signals, which depends on the realization of the state $\theta_1$, is characterized by a parameter $r$, which determines the precision of this signal and is analogous to the parameter $\tau_1$ for the continuous model. Table 2 contains the conditional probabilities, for each agent, of observing a signal $x_1^i \in \{l_1, m_1, h_1\}$, given the realization of the state $\theta_1 \in \{L_1, M_1, H_1\}$. I assume that $r > \frac{1}{3}$ so that the signals and states are positively correlated.

| $\Pr(l_1|$) | $L_1$ | $M_1$ | $H_1$ |
|-------------|------|------|------|
| $r$         | $(1-r)\frac{2}{2}$ | $(1-r)\frac{2}{2}$ | $r$ |
| $\Pr(m_1|$) | $(1-r)\frac{2}{2}$ | $r$ | $(1-r)\frac{2}{2}$ |
| $\Pr(h_1|$) | $(1-r)\frac{2}{2}$ | $(1-r)\frac{2}{2}$ | $r$ |

Table 2: Conditional distribution of private signals, Country 1

For the discrete model the characterization of equilibria in Country 1 will depend on the specific combination of parameters. Although there can be multiple equilibria, I choose parameters for the experiment that ensure a unique equilibrium in monotone strategies. Depending on parameters, in equilibrium agents will follow one of the 4 possible monotonic strategies: always withdraw ($a_1^i(x_1^i) = 0$, for all $x_1^i$), roll over only for high signals ($a_1^i(x_1^i) = 0$ if $x_1^i \in \{l_1, m_1\}$, $a_1^i(h_1) = 1$), roll over for low and medium signals ($a_1^i(l_1) = 0, a_1^i(x_1^i) = 1$ if $x_1^i \in \{m_1, h_1\}$), or always roll over ($a_1^i(x_1^i) = 1$, for all $x_1^i$).

2.2.2 Country 2

Just as in the continuous model, the state in Country 2 depends on the realization of the state in Country 1. The non-negative correlation between states is measured by a parameter, $s \geq \frac{1}{3}$, which is analogous to the parameter $\tau_2$ in the continuous model. In particular, the probability distribution for the state in Country 2, $\theta_2 \in \{L_2, M_2, H_2\}$, given the realization of the state in Country 1, $\theta_1 \in \{L_1, M_1, H_1\}$, is presented in table 3:

The parameter $s \geq 1/3$ determines the correlation between fundamentals, i.e. if $s = 1$ fundamentals are perfectly correlated and if $s = 1/3$ there is no correlation between
fundamentals. Notice that agents in Country 2 should only take into account the information related to Country 1 (the prior distribution and the signal about behavior in Country 1) when \( s > 1/3 \). Therefore, \( s \) will serve as a treatment variable for the experiment that will determine the strength of the fundamental channel of contagion.

Agents in Country 2 also observe a public signal about the number of agents in Country 1 that withdraw their funds. Given that there are only 2 players in each country, let \( w \in \{0, 1, 2\} \) be the true number of withdrawals in Country 1 and \( y \in \{0, 1, 2\} \) be the noisy signal that agents in Country 2 observe about \( w \). I assume that, given the state in Country 1, agents in Country 2 learn the true number of withdrawals (i.e. \( w = y \)) with probability \( \alpha \), and they observe either of the two incorrect numbers each with probability \( (1-\alpha)/2 \). Therefore, \( \alpha \geq 1/3 \) measures the precision of this signal and is analogous to the parameter \( \eta \) in the continuous model. If \( \alpha = 1 \) this signal is perfectly precise and agents in Country 2 observe exactly what agents in Country 1 did, but if \( \alpha = 1/3 \) this signal is completely uninformative, since, regardless of the true actions of agents in Country 1, agents in Country 2 observe any of the 3 possible signals with the same probability. Table 4 contains this probability distribution:

<table>
<thead>
<tr>
<th>( w )</th>
<th>( w = 0 )</th>
<th>( w = 1 )</th>
<th>( w = 2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Pr (y = 0</td>
<td>\theta_1, \cdot) )</td>
<td>( \alpha )</td>
<td>( (1-\alpha)/2 )</td>
</tr>
<tr>
<td>( \Pr (y = 1</td>
<td>\theta_1, \cdot) )</td>
<td>( (1-\alpha)/2 )</td>
<td>( \alpha )</td>
</tr>
<tr>
<td>( \Pr (y = 2</td>
<td>\theta_1, \cdot) )</td>
<td>( (1-\alpha)/2 )</td>
<td>( (1-\alpha)/2 )</td>
</tr>
</tbody>
</table>

Table 4: Conditional distribution of the public signal about behavior in Country 1, for Country 2

Observing signal \( y \) allows agents in Country 2 to update their beliefs about the realized state in Country 1, \( \theta_1 \), as long as \( \alpha > 1/3 \) and \( s > 1/3 \).

Finally, agents in Country 2 also observe a noisy private signal about \( \theta_2 \), which, for simplicity, has the same structure as the private signal for agents in Country 1. The precision of this signal, \( r > 1/3 \), is assumed to be the same in both countries. The probability distribution of private signals \( x_2^i \in \{l_2, m_2, h_2\} \), given the state \( \theta_2 \) is then analogous to table 2 for Country 1.

Just as in Country 1, the parameters in the experiment are chosen such that there is a unique equilibrium in monotone strategies in Country 2. The actions taken by agents in Country 2 depend on private (\( x_2^i \)) and public (\( y \)) signals. Depending on parameters, agents will have a unique symmetric equilibrium where they follow monotonic strategies.
Monotonicity will arise in both private and public signals in the following way. For a given public signal \( y \), the monotonicity of actions with respect to private signals \( x_i^j \in \{l_2, m_2, h_2\} \) establishes a higher probability of withdrawing for low signals than for medium, than for high signals:

\[
\Pr(a_i^j = 0| l_2, y) \geq \Pr(a_i^j = 0| m_2, y) \geq \Pr(a_i^j = 0| h_2, y)
\]

where \( a_i^j = 0 \) corresponds to agent \( i \) choosing to withdraw.

For a given private signal \( x_i^j \), the monotonicity of actions with respect to the public signal \( y \in \{0, 1, 2\} \) establishes a higher probability of withdrawing after observing a signal that states that 2 agents withdraw, than one that states that 1 agent withdraw, than one that states that 0 agents withdraw in Country 1:

\[
\Pr(a_i^j = 0| x_i^j, 2) \geq \Pr(a_i^j = 0| x_i^j, 1) \geq \Pr(a_i^j = 0| x_i^j, 0)
\]

The specific ordering of signals in equilibrium, in terms of combinations of \( x_i^j \) and \( y \), will depend on the parameters chosen.

3 Experimental procedures

3.1 Parameters used in the experiment

The payoff of withdrawing is equal to 4 (\( \lambda_1 = \lambda_2 = 4 \)), and the payoff of rolling over when the country stays solvent is equal to 20 in both countries (\( \gamma_1 = \gamma_2 = 20 \)).

As mentioned above, the main treatment variables used in the experiment are the ones measuring the strength of the two channels of contagion that we are interested in studying: \( s \) and \( \alpha \). I use 5 different combinations of these parameters to study these two channels: \((s, \alpha) \in \{(1/3, 1/3), (3/4, 1/3), (1/3, 3/4), (3/4, 3/4), (1, 1)\}\). In the first three cases at least one of the channels is switched off because either the states are uncorrelated (\( s = 1/3 \)), the signal about behavior of agents in Country 1 is uninformative (\( \alpha = 1/3 \)), or both. Notice that in the third case, even if the signal about behavior of agents in Country 1 is informative (\( \alpha = 3/4 \)), as long as the states are uncorrelated (\( s = 1/3 \)), both the fundamental and the social learning channels are switched off, so subjects in Country 2 should disregard the information coming from the prior about the state in Country 1 and the signal \( y \). Given the importance of prior beliefs on the comparative statics for the model with a continuum of agents, in the experiment I induce two types of prior beliefs about the state in Country 1, one optimistic and one pessimistic. The probability distributions corresponding to optimistic and pessimistic prior beliefs about are the state in Country 1 are given in table 5:

<table>
<thead>
<tr>
<th></th>
<th>Optimistic prior</th>
<th></th>
<th>Pessimistic prior</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Pr(L_1) )</td>
<td>17.5%</td>
<td>( \Pr(M_1) )</td>
<td>17.5%</td>
</tr>
<tr>
<td>( \Pr(H_1) )</td>
<td>65%</td>
<td>( \Pr(L_1) )</td>
<td>65%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \Pr(M_1) )</td>
<td>17.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \Pr(H_1) )</td>
<td>17.5%</td>
</tr>
</tbody>
</table>

Table 5: Prior probability distributions

The precision of the private signals in each country is determined by \( r = 6/10 \). Therefore, from table 2, in each country, the probability of observing a private signal that is consistent
with the realization of the state is $6/10$, and the probability of observing either of the two inconsistent signals is equal to $2/10$, respectively.

The next section describes in detail the experimental procedures and the design of the different treatments that compose the experiment.

### 3.2 Experimental design

The experiment was conducted at the Center for Experimental Social Science at New York University during 2013 using the usual computerized recruiting procedures. All subjects were undergraduate students from New York University. Each session lasted approximately 45 minutes and subjects earned on average $17, including a $5 show up fee.\(^{11}\)

I implemented a between subjects design in order to directly compare the behavior of subjects across treatments. Each session consisted of 30 independent and identical rounds where subjects were randomly matched in pairs in every round. The main treatment variables are the correlation between fundamentals ($s$) and the precision of the signal about the behavior of agents in Country 1 ($\alpha$). As explained above, an important lesson learnt from the theoretical analysis of the continuous model is the central role that prior beliefs play on the decisions of agents when varying the strength of the fundamental and social learning channels. For this reason, every combination of ($s, \alpha$) used in the different treatments of the experiment was run twice, one for a session where prior optimistic beliefs were induced, and one where prior pessimistic beliefs were induced.

One session (24 subjects) was run with subjects making decisions for Country 1, for each of these two types of prior beliefs (see table 5 for parameters). Since the focus of this study is to understand the behavior of agents in Country 2, the same baseline session of Country 1 (30 rounds) was used for every session of Country 2, for each of these two types of prior beliefs. In each round, each pair of subjects in a Country 2 session was randomly assigned a pair of subjects from the Country 1 session with the corresponding prior beliefs. These observations coming from Country 1 pairs characterize both the fundamental state in Country 1 ($\theta_1$) and the number of withdrawals in Country 1, that, depending on the parameters $s$ and $\alpha$, would determine the state in Country 2 and the public signal that subjects in Country 2 receive about the behavior of that specific pair of subjects in Country 1. In this way, every observation from pairs that participated in Country 1 sessions was used as the base for one pair of subjects in each Country 2 session. Since subjects were randomly matched in pairs in every round and the matching of pairs from Country 1 to Country 2 sessions was done randomly, the one-shot feature of the game was preserved in every round. In other words, subjects should not condition their decisions on past performance of their opponent or of subjects in Country 1, since in each round they receive information about a new set of subjects from another session and are matched with a new person in the room.

Subjects in Country 2 were also told in the instructions the precise way in which the state $\theta_2$ depended on the state in the previous experiment and they were told in detail the information structure of the game and the distinction between the public signal about the behavior of agents in the previous experiment and their private signal about the state that was being drawn for them in that session. In each round, they observed at the same time

\(^{11}\)Instructions can be found in: https://files.nyu.edu/it384/public/instructions_all.pdf
the public signal about the behavior of the subjects in the previous experiment and their private signal about their payoff relevant state, $\theta_2$. Notice that the induced prior beliefs, coming from the unconditional probability distribution about the state in Country 1, are held fixed throughout the entire session. It is important to clarify that the prior, just as the signal about the behavior of subjects in Country 1, is public information, i.e. both pair members observe the same information. This is in contrast to the private signal, which is drawn independently for each subject.

To avoid framing effects, the game was explained using neutral terms. Subjects were told to choose between two actions $A$ (roll over) or $B$ (withdraw), avoiding terminology such as “withdraw”, “roll over” or “default”.

In each session, subjects entered the laboratory and the instructions were read out loud. In each round a different state was drawn according to the probability distributions from the previous section and subjects were randomly and anonymously matched with another person in the room. For the sessions related to Country 1, in each round, a subject observed her private signal about the state in Country 1 and had to make a choice between actions $A$ and $B$. For the sessions related to Country 2, in each round a subject observed her private signal about the state in Country 2 and a public signal about the actions taken by a randomly chosen pair of subjects in that same round that participated in a Country 1 session. Since choices were simultaneously made, subjects did not observe the choice of their pair member. After each round they received feedback about the realization of the state, the signals they observed, the outcome of the game, and their individual payoff for the round. For Country 1, the feedback was the private signal observed by the subject, $x_i^1$, the realized state in Country 1, $\theta_1$, the subject’s choice of action, whether action $A$ was successful or not, and the subject’s individual payoff for the round. The feedback for Country 2 sessions was analogous to the one for Country 1 sessions but it included, in addition, the public signal that the subject observed about the behavior of subjects in Country 1 and the true behavior of subjects in Country 1.\footnote{To avoid framing effects or any type of connotations, instead of telling subjects the number of people that took action $B$ (withdraw) in the pair that was assigned to them from Country 1, subjects were told one of these 3 signals: “0 chose action $A$, 2 chose action $B$”, “1 chose action $A$, 1 chose action $B$” or “2 chose action $A$, 0 chose action $B$”.}

The computer randomly selected three of the rounds played (one from rounds 1-10, one from 11-20, and one from 21-30) and subjects were paid the average of the payoffs obtained in those rounds. All parameters in the experiment where expressed in dollar amounts. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

Overall, there were a total of 276 participants. Table 6 summarizes the experimental design and contains the equilibrium predictions for each treatment in Country 1 and Country 2.

### 4 Experimental results

I analyze the results of the experiment to understand the behavioral forces related to fundamentals and social learning that underlie contagious episodes in the context of this model. It is important to note, however, that the purpose of this study is not just to test a theoretical
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Induced prior</th>
<th>Correlation of states (s)</th>
<th>Precision of y (α)</th>
<th># subjects</th>
<th>Equilibrium actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1: 1</td>
<td>Optimistic</td>
<td>-</td>
<td>-</td>
<td>24</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C1: 2</td>
<td>Pessimistic</td>
<td>-</td>
<td>-</td>
<td>24</td>
<td>Roll over for x=m and x=h</td>
</tr>
<tr>
<td>C2: 1</td>
<td>Optimistic</td>
<td>Uninformative (1/3)</td>
<td>Uninformative (1/3)</td>
<td>20</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 2</td>
<td>Optimistic</td>
<td>High (3/4)</td>
<td>Uninformative (1/3)</td>
<td>24</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 3</td>
<td>Optimistic</td>
<td>Uninformative (1/3)</td>
<td>High (3/4)</td>
<td>24</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 4</td>
<td>Optimistic</td>
<td>High (3/4)</td>
<td>High (3/4)</td>
<td>24</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 5</td>
<td>Optimistic</td>
<td>Perfect (1)</td>
<td>Perfect (1)</td>
<td>20</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 6</td>
<td>Pessimistic</td>
<td>Uninformative (1/3)</td>
<td>Uninformative (1/3)</td>
<td>22</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 7</td>
<td>Pessimistic</td>
<td>High (3/4)</td>
<td>Uninformative (1/3)</td>
<td>24</td>
<td>Roll over for x=m and x=h</td>
</tr>
<tr>
<td>C2: 8</td>
<td>Pessimistic</td>
<td>Uninformative (1/3)</td>
<td>High (3/4)</td>
<td>26</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 9</td>
<td>Pessimistic</td>
<td>High (3/4)</td>
<td>High (3/4)</td>
<td>20</td>
<td>Roll over for y=0, y=1&amp;x=h</td>
</tr>
<tr>
<td>C2: 10</td>
<td>Pessimistic</td>
<td>Perfect (1)</td>
<td>Perfect (1)</td>
<td>24</td>
<td>Roll over for y=0</td>
</tr>
</tbody>
</table>

Table 6: Experimental treatments and equilibrium predictions
model experimentally, but rather to use the stylized model of global games as a guide to study the type of behavior that can arise when varying the strength of the two channels of contagion.

First, I briefly describe the behavior of subjects in Country 1 and establish whether there is an effect in behavior from inducing an optimistic versus a pessimistic prior. Then I study the behavior of subjects in Country 2 by testing two main hypotheses that focus on the role of fundamentals and social learning in financial contagion and their effects in terms of welfare. The study of these hypotheses will shed light on the behavioral sources that determine empirically the strength of these channels and their consequences in terms of welfare. I then compare comparative statics in the data with the theoretical predictions. Additionally, I analyze individual strategies to classify subjects into five types to study if equilibrium play is optimal in terms of realized payoffs, given the distribution of types in the sample.

Unless otherwise specified, results will be presented for the last 20 rounds played by subjects to allow for behavior to stabilize.

4.1 Country 1

The main question when analyzing Country 1 sessions is whether subjects behave differently given an optimistic or a pessimistic prior. I find significant differences in these two treatments in the expected direction. Table 7 contains the percentage of total decisions to roll over for each private signal observed in the last 20 rounds of the experiment, for each of these treatments.

<table>
<thead>
<tr>
<th>Signal</th>
<th>Optimistic prior</th>
<th>Pessimistic prior</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>31.97%</td>
<td>13.15%</td>
</tr>
<tr>
<td>medium</td>
<td>100%</td>
<td>61.83%</td>
</tr>
<tr>
<td>high</td>
<td>100%</td>
<td>92.65%</td>
</tr>
</tbody>
</table>

Table 7: Percentage of rollover decisions, by signal, by treatment, C1

As we can see, for each signal observed there is a significantly lower proportion of decisions to roll over when the prior beliefs over the state in Country 1 are pessimistic than when they are optimistic (the pairwise comparisons across treatments are statistically different to the 1% level of significance). This is in line with the qualitative predictions of a higher incidence of decisions to roll over under optimistic priors.

We also observe a significantly lower rate of default for the intermediate state (θ₁ = M₁) for the optimistic prior than for the pessimistic prior (16.67% compared to 61.67%), significant to the 1% level of significance.¹³

Subjects in Country 1 sessions behave in accordance to the existing experimental results on standard global games (see Heinemann, Nagel and Ockenfels, 2004). Across treatments,

¹³Note that the relevant state to study rates of default is only the intermediate state where θ₁ = M₁, since in this case default requires agents to miscoordinate on their decision to rollover (at least one of them has to withdraw). When the state is low (θ₁ = L₁) default always occurs and when the state is high (θ₁ = H₁) default never occurs, irrespective of the actions of agents.
85% of subjects use threshold strategies, and 50% of total strategies coincide with the equilibrium prediction, for each treatment.

Even if we do not observe subjects in Country 1 taking exactly the actions suggested by the theory (rolling over for all signals when facing an optimistic prior; rolling over for medium and high signals and withdrawing for low signals when facing a pessimistic prior), we observe a significant difference in behavior arising from the different priors in the direction prescribed by the theory. When analyzing the aggregate behavior of subjects that participated in the different sessions corresponding to Country 2, I will compare their observed actions to the theoretical equilibrium predictions, as defined in table 6. However, in section 5.2.3 when I disaggregate the data to study individual strategies, I distinguish two types of equilibrium strategies for subjects in Country 2, one corresponding to the equilibrium prescribed in table 6, which assumes that subjects in Country 1 behaved according to equilibrium, and one alternative strategy that corresponds to the equilibrium in Country 2 when agents in Country 2 believe that agents in Country 1 behave exactly as table 7 indicates. This, of course, matters only in the treatments where the states are positively correlated ($s > 1/3$) and the signal about the behavior of agents in Country 1 is precise ($\alpha > 1/3$).

### 4.2 Country 2

I now analyze the behavior of subjects that participated in Country 2 sessions. The two channels of contagion studied in this paper are closely related to two signals received by subjects. Recall that subjects receive three signals about the state, and, depending on the treatment, they should take all of these or only a subset of them into account for their decision. These signals are: the induced prior about the state in Country 1 (optimistic vs pessimistic), which is related to the fundamental channel of contagion, the public signal about the behavior of agents in Country 1 ($y \in \{0, 1, 2\}$), related to the social learning channel of contagion, and the private signal about the realized state in Country 2 ($x^*_2 \in \{l^*_2, m^*_2, h^*_2\}$). Since the private signal is always informative about the state $b^*_2$, in all treatments subjects should take it into account for their decision. The aim of the first hypothesis investigated in the data is to characterize the situations where the signals corresponding to the two channels of contagion should be taken into account for decisions or not. I will refer to these instances as cases where subjects should switch on or off each of the channels of contagion. Switching off the fundamental channel of contagion means not taking into account the induced prior (optimistic vs pessimistic), and switching off the social learning channel of contagion means not taking into account the signal about the behavior of agents in Country 1. Switching them on means that these signals should determine decisions.

**Hypothesis 1** Subjects switch on the fundamental channel of contagion whenever the states are correlated ($s > 1/3$). Subjects switch on the social learning channel of contagion when the states are correlated ($s > 1/3$) and the signal about the behavior in Country 1 is precise ($\alpha > 1/3$).

As we will see in table 8, we cannot establish full support for this hypothesis in the data. The observed departures from these predictions imply two systematic biases that have a direct relationship with each of the two channels of contagion. The first one relates
to the fundamental channel since subjects do not take into account the induced prior in situations where they should, i.e., when the states are correlated \((s > 1/3)\). In this case subjects exhibit a base rate neglect bias since they underweight the information contained in the prior probability distribution and put more weight on new information (see Kahneman and Tversky, 1973, 1980, and Bar-Hillel, 1980). The second bias observed in the data is related to social learning and corresponds to overreaction to the signal about the behavior of agents in Country 1, \(y\), in treatments where this signal is completely uninformative. The social learning signal is uninformative either because it is uncorrelated to the true behavior of subjects in Country 1 \((\alpha = 1/3)\), or because the states are uncorrelated \((s = 1/3)\), in which case this signal does not carry any relevant information for subjects in Country 2, irrespective of its precision.

To illustrate how these biases arise in the data, table 8 reports the results of five random effects logit regressions that test hypothesis 1. For all regressions the dependent variable is the probability to choose roll over. The independent variables are: the private signals \(x_2^i\), the public signal about the number of agents who rolled over in Country 1, \(y_{\text{rollover}}\), a dummy variable \(d_{\text{prior}}\) that takes the value of 0 for an induced optimistic prior and a value of 1 for an induced pessimistic prior, and two interacted terms of this dummy with the private signal \(x_2^i\) and with the public signal about the proportion of agents that roll over, \(y_{\text{rollover}}\). The five specifications differ in the combination of \((s, \alpha)\) parameters that define each treatment (as in table 6). In each of these specifications I pool the data from sessions where an optimistic and a pessimistic prior were induced. I test whether there is a significant difference in behavior under these priors by looking at the coefficient of the dummy \(d_{\text{prior}}\). The numbers in bold indicate departures, in terms of significance, from the expected results. This can be either because coefficients that should be significant are not, or because coefficients that should not be significant are significant. These results identify the emergence of the biases described above. Table 9 contains the marginal effects of these regressions.

From table 8 we can observe that subjects seem to be taking into account the signal about the behavior of agents in Country 1 for their decision in all treatments. This signal is informative and should be taken into consideration only in the cases where the states are positively correlated \((s > 1/3)\) and this signal is informative \((\alpha > 1/3)\). We see, for the coefficients in bold, that this signal is a significant determinant of choices even for the treatments where it should not be taken into account. Therefore, we can identify a bias of overreaction to this signal for cases where the states are uncorrelated and/or this signal is uninformative. Notice in table 9, however, that the size of the bias, measured by the magnitude of the marginal effects of \(y_{\text{rollover}}\), is almost twice as large for the case where \(\alpha = 3/4\) and \(s = 1/3\) (specification 3), than for the cases where \(\alpha = 1/3\) (specifications 1 and 2). This could be due to the fact that the signal’s lack of information for subjects is more salient when \(\alpha = 1/3\), i.e., when it is explained that this signal is not correlated with the true behavior of agents in Country 1, which is probably why we see a weaker response to it than when \(\alpha > 1/3\). When \(\alpha = 3/4\) this signal is giving accurate information about the behavior of agents in Country 1, but subjects have to realize that this information is irrelevant since the fundamentals in both countries are uncorrelated when \(s = 1/3\). For simplicity, in the remainder of the paper I will refer to this overreaction bias as the social learning bias.
Table 8: Logit estimates of information taken into account for individual actions, by treatment

The other bias that we can identify from table 8 is a type of base rate neglect: subjects do not use the information contained in the prior for their decision. We can identify the emergence of this bias qualitatively by the lack of statistical significance of the coefficients for the dummy that differentiates the two treatments according to the prior, $d_{prior}$. Regardless of the social learning signal, subjects in Country 2 should take the information of the prior into account as long as the fundamentals are positively correlated ($s > \frac{1}{3}$). This means that we should see the coefficients related to $d_{prior}$ to be statistically different from zero in specifications 2, 4, and 5. Notice that this is the case only for specification 5. In specifications 2 and 4, where $s = \frac{3}{4}$, we see no statistical difference in behavior arising from sessions where subjects had an induced optimistic prior and sessions where they had an induced pessimistic prior. This effectively means that, even if the states are highly correlated, with a 75% chance of the state in Country 2 to coincide with the realization of the state in Country 1, subjects fail to include the information contained in the prior probability distribution over the state in Country 1 on their expectations about the state in Country 2. This is a clear example of the bias known as base rate neglect, first introduced by Kahneman and Tversky (1973) and reviewed by Bar-Hillel (1980, 1990), which has been well documented in individual decision making tasks. For simplicity, in the remainder of the paper I will refer to this as the fundamental bias. It is interesting to notice, however, that in the treatment where both signals are perfectly informative (specification 5) we do not find these biases anymore, in terms of significance.\footnote{This does not rule out the possibility that there might be a bias in terms of magnitude, i.e. that even if subjects take into account the relevant information, they might not do it in the way predicted by the theory.}

\begin{table}[h]
\centering
\begin{tabular}{cccccc}
\hline
 & 1 & 2 & 3 & 4 & 5 \\
\hline
$s = 1/3$ & $s = 3/4$ & $s = 1/3$ & $s = 3/4$ & $s = 1$ \\
$\alpha = 1/3$ & $\alpha = 1/3$ & $\alpha = 3/4$ & $\alpha = 3/4$ & $\alpha = 1$ \\
\hline
$x_2^i$ & 3.211*** & 3.943*** & 3.973*** & 3.236*** & 2.303*** \\
 & (0.337) & (0.417) & (0.41) & (0.369) & (0.304) \\
$y_{rollover}$ & 0.646*** & 0.696*** & 1.246*** & 1.876*** & 1.048*** \\
 & (0.215) & (0.254) & (0.262) & (0.291) & (0.32) \\
$d_{prior}$ & -0.345 & -0.796 & -0.224 & -0.373 & -2.952*** \\
 & (0.939) & (0.797) & (0.871) & (0.875) & (0.819) \\
$d_{prior} \times x_i$ & 0.387 & -0.239 & -0.561 & 0.222 & 0.213 \\
 & (0.49) & (0.501) & (0.49) & (0.493) & (0.385) \\
$d_{prior} \times y_{roll}$ & 0.574* & 0.056 & 0.408 & -0.293 & 1.079*** \\
 & (0.319) & (0.328) & (0.348) & (0.385) & (0.404) \\
 & (0.665) & (0.593) & (0.661) & (0.633) & (0.634) \\
$N$ & 840 & 960 & 1000 & 880 & 880 \\
\hline
\end{tabular}
\caption{Clustered (by subject) standard errors in parentheses}
\begin{flushright}
* significant at 10%; ** significant at 5%; *** significant at 1%
\end{flushright}
\end{table}
signals are highly informative, but where some noise still remains, it is interesting to notice that only in that case does this bias arise. This might have interesting implications about the type of informational environments that are more prone to exhibit this fundamental bias, in particular about the increased likelihood of observing this bias as the uncertainty in the environment increases.

It is important to note that the qualitative results presented in table 8 do not change when controlling for risk aversion (see table 13 in the appendix).\textsuperscript{15} We see the same biases arise in all the specifications above, and the coefficients related to these biases to be very similar to those in table 8 when we include risk aversion as an independent variable. Therefore, we can conclude that these biases cannot be explained through risk aversion.

With these results in hand, we can turn our attention to the second hypothesis that investigates welfare implications. I analyze frequencies of withdrawals and realized payoffs in order to study welfare by comparing these two measures to two benchmarks: the theoretical equilibrium and the first best allocation by the social planner.

**Hypothesis 2** The frequencies of withdrawals and the mean payoffs of subjects in the experiment are consistent with the equilibrium predictions, given the realization of states and signals in the experiment.

To calculate the equilibrium frequencies of withdrawals, in each treatment I determine the instances where subjects should withdraw according to the equilibrium strategy (see table 6), for the realization of states and signals in the experiment. Likewise, given the realization of states in the experiment, the frequencies of withdrawals for the first best benchmark

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\textsuperscript{15}The risk aversion coefficient in table 13 corresponds to the switching point of the risk measure of Holt and Laury (2002).
correspond to the cases where the realized state is low (the solution of the social planner is for agents to withdraw when the state is low \( \theta_2 = L_2 \) and roll over when the state is either medium or high \( \theta_2 \in \{M_2, H_2\} \)).

For each treatment, panel A of table 10 compares the observed frequency of withdrawals to the equilibrium predictions and the first best allocation. The numbers in parentheses are the proportion of instances where the observed or equilibrium withdrawals coincide with withdrawals according to the first best allocation. The higher this number, the more instances of withdrawals coincide with the first best allocation, and thus the smaller is the loss in terms of welfare.

The results in table 10, panel A, do not support hypothesis 2. For all but one case (pessimistic prior, \( s = 1/3, \alpha = 3/4 \)) the observed frequency of withdrawals is statistically different from the equilibrium predictions. However, if we compare the percentage of observed withdrawals to the percentage of withdrawals that would arise under the first best allocation, we observe that in half of the treatments these numbers are not statistically different. This means that the number of instances where subjects in the experiment choose to withdraw is similar to the number of times that the social planner would do so. However, it does not mean that they are doing so in those situations that the planner would. In fact, subjects in the experiment many times make the wrong decisions, which is shown by the numbers in parentheses. The larger this number, the less discrepancies with the first best frequencies of withdrawals. On average, there are more discrepancies when the prior is optimistic than when it is pessimistic. Notice as well that the discrepancies between the equilibrium frequencies of withdrawals and those corresponding to the first best allocation are also large, which illustrates the well known result about the inefficiency of the equilibrium in global games.

Another indicator of welfare based on performance is the mean realized payoff of subjects. Panel B in table 10 contains the mean realized payoff of subjects in the experiment and the mean realized payoffs that would arise under equilibrium strategies and the first best allocation, for the observed states and signals in each treatment of the experiment. Similar to panel A of table 10, the number in parentheses under the realized payoffs in the experiment and under the payoffs corresponding to equilibrium is a measure of relative performance with respect to the first best allocation. In this case, this number corresponds to the fraction of first best payoffs that are achieved in each of these cases, i.e. it is the ratio of mean realized payoffs (or equilibrium payoffs) to the mean first best payoffs. These numbers can be thought of as an index of welfare loss: the larger the number, the smaller is the loss.

We can see from panel B in table 10 that in all but two cases (pessimistic prior, \( (s, \alpha) \in \{(3/4, 3/4), (1, 1)\} \)) the mean realized payoffs in the experiment are statistically lower than the mean payoffs that would have arisen if subjects had followed the equilibrium strategies, and in all cases payoffs are statistically lower than those corresponding to the first best allocation. To determine the welfare losses for subjects associated to departures from equilibrium behavior I look at the ratio of realized payoffs to first best payoffs and the ratio of equilibrium payoffs to first best payoffs to compare the welfare loss associated to playing equilibrium to the welfare loss of subjects in the experiment. Subjects in the experiment exhibit significant welfare losses by departing from the equilibrium strategies in all but two treatments. In these two treatments, corresponding to a pessimistic prior, high or perfect correlation of states \( s \in \{3/4, 1\} \) and highly or perfectly precise signals about behavior of
<table>
<thead>
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<th>Pessimistic prior</th>
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<td>$s = 1/3$</td>
<td>$s = 3/4$</td>
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<tr>
<td>$\alpha = 1/3$</td>
<td>$25.83%$</td>
<td>$29.17%$</td>
</tr>
<tr>
<td>$\alpha = 3/4$</td>
<td>$(0.493)$</td>
<td>$(0.355)$</td>
</tr>
<tr>
<td>Observed</td>
<td>$36%$</td>
<td>$23.83%$</td>
</tr>
<tr>
<td></td>
<td>$(0.493)$</td>
<td>$(0.355)$</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>$0%***$</td>
<td>$0%***$</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>First best</td>
<td>$35%$</td>
<td>$19.17%***$</td>
</tr>
</tbody>
</table>

* significant at 10%; ** significant at 5%; *** significant at 1%; statistical difference with respect to observed rate of withdrawals

Panel A: Frequency of withdrawals

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<th>Pessimistic prior</th>
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<td></td>
<td>$s = 1/3$</td>
<td>$s = 3/4$</td>
</tr>
<tr>
<td>$\alpha = 1/3$</td>
<td>$9.29$</td>
<td>$12.82$</td>
</tr>
<tr>
<td>$\alpha = 3/4$</td>
<td>$(0.645)$</td>
<td>$(0.757)$</td>
</tr>
<tr>
<td>Observed</td>
<td>$9.29$</td>
<td>$12.82$</td>
</tr>
<tr>
<td></td>
<td>$(0.645)$</td>
<td>$(0.757)$</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>$13%***$</td>
<td>$16.17%***$</td>
</tr>
<tr>
<td></td>
<td>$(0.903)$</td>
<td>$(0.955)$</td>
</tr>
<tr>
<td>First best</td>
<td>$14.4%***$</td>
<td>$16.93%***$</td>
</tr>
</tbody>
</table>

* significant at 10%; ** significant at 5%; *** significant at 1%; statistical difference with respect to observed payoffs

Panel B: Mean payoffs

Table 10: Comparison of frequencies of withdrawals and mean payoffs to equilibrium and efficiency benchmarks, by treatment
agents in Country 1 ($\alpha \in \{3/4, 1\}$), we observe a significant gain in terms of welfare from departing from the equilibrium strategies.

Given the results presented when studying hypothesis 1, it is not surprising to see departures from the predictions of hypothesis 2. We see from table 10 higher frequencies of withdrawals and lower realized payoffs in the data than in equilibrium in most treatments. However, we also observe some cases where the payoffs associated to equilibrium are not significantly higher than the ones realized by subjects, and in one case there is even a gain from such a departures. This raises a question related to the use given by subjects to the information they observe. Since there is a systematic overreaction to the social learning signal, in the next subsection I analyze the way in which this signal affects the decisions of subjects to measure the cost induced by the social learning bias.

4.2.1 Social learning: The cost of following others

In this subsection I look at the cost, in terms of foregone payoffs, that arises when subjects take the opposite action than the one prescribed by the theoretical equilibrium after they observe a signal that indicates that at least 1 or exactly 2 of the subjects in Country 1 took that action. We can identify two types of mistakes: (1) withdrawing after observing a signal of agents withdrawing in Country 1, when the equilibrium action is to roll over, and (2) rolling over after observing a signal of agents in Country 1 rolling over, when the equilibrium action is to withdraw. Mistake (1) can be thought of as a contagious panic, since subjects react negatively in their own country after observing signals of distress in a foreign country. Mistake (2) illustrates a case of contagious confidence, since agents take actions that imply confidence in their country after observing agents in a foreign country showing confidence in their own market. Notice that these two types of mistakes correspond to “irrational” contagion due to the social learning bias.

I analyze four cases. The first two correspond to mistake (1), the third and fourth correspond to mistake (2). The first case is when subjects observe signals for which they would roll over if they followed the equilibrium actions, but observe a signal that tells them that at least one subject in Country 1 withdrew and they withdraw as well. The second case is the same as the first case, except that the signal they observe informs them that exactly both subjects from Country 1 withdrew. The third and fourth cases are analogous to the first two, but in these cases subjects observe a signal that tells them that subjects in Country 1 have rolled over and as a result they roll over when the equilibrium action would be to withdraw, given the signals that they observe.

Table 11 reports the mean payoffs associated with each of these four cases, for each treatment, as well as the mean payoff that would have arisen from following the equilibrium strategy in those instances. Table 11 also reports the frequency of such instances with respect to the total number of decisions in the last 20 rounds of each treatment.

We see from table 11 that in all treatments where an optimistic prior is induced, and in those where a pessimistic prior is induced and the states are uncorrelated ($s = 1/3$), there is a significant loss in terms of payoffs by following withdrawals in Country 1. This is a clear illustration of the pervasive effects of the social learning channel of contagion through the emergence of irrational panics. However, when subjects have a pessimistic prior, the states
<table>
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<td>α = 1/3</td>
<td>α = 1/3</td>
<td>α = 3/4</td>
<td>α = 3/4</td>
<td>α = 1</td>
</tr>
<tr>
<td>Follow 1 withdraw</td>
<td>4***</td>
<td>4***</td>
<td>4**</td>
<td>4***</td>
<td>4***</td>
<td>4***</td>
<td>4***</td>
<td>4***</td>
<td>4***</td>
<td>4***</td>
</tr>
<tr>
<td>Eq. (roll over)</td>
<td>11.11</td>
<td>13.41</td>
<td>11.71</td>
<td>13.43</td>
<td>8.87</td>
<td>10.09</td>
<td>9.37</td>
<td>10.44</td>
<td>10</td>
<td>-</td>
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<tr>
<td>% total decisions</td>
<td>24.75%</td>
<td>17.08%</td>
<td>17.08%</td>
<td>14.58%</td>
<td>7.5%</td>
<td>26.59%</td>
<td>6.67%</td>
<td>30.58%</td>
<td>0.5%</td>
<td>-</td>
</tr>
<tr>
<td>Follow 2 withdraw</td>
<td>4***</td>
<td>4***</td>
<td>4*</td>
<td>4***</td>
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<td>4***</td>
<td>4</td>
<td>4***</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Eq. (roll over)</td>
<td>13</td>
<td>13.78</td>
<td>12.31</td>
<td>12.41</td>
<td>5.71</td>
<td>10</td>
<td>4.29</td>
<td>12.31</td>
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<td>-</td>
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<tr>
<td>% total decisions</td>
<td>15%</td>
<td>9.38%</td>
<td>5.42%</td>
<td>6.04%</td>
<td>1.75%</td>
<td>13.64%</td>
<td>2.92%</td>
<td>17.5%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* significant at 10%; ** significant at 5%; *** significant at 1%; statistical difference with respect to the payoff of following equilibrium strategies

Table 11: Payoffs of following others, by treatment
are correlated \((s \in \{3/4, 1\})\) and the signal about behavior in Country 1 is informative \((\alpha \in \{3/4, 1\})\), we see a positive effect in terms of payoffs as a consequence of the mistakes associated with the social learning bias.

These two treatments are the only ones that exhibit a significantly lower rate of withdrawals with respect to equilibrium and to the first best allocation, as shown in table 10 above. These cases show evidence of contagious confidence, or positive contagion, where subjects choose to roll over after observing a signal of at least one subject rolling over in Country 1, even if the equilibrium strategies prescribe withdrawals. This increase in confidence leads agents to increase their payoffs as a consequence of more successful coordination.

### 4.2.2 Optimality of equilibrium play, given distribution of subjects

The results presented so far have focused on the aggregate data. The comparisons made to the discrete equilibrium benchmark in table 10 are based on the hypothetical outcomes corresponding to the case where all subjects in the sample behave according to equilibrium, for the realized states and signals in the experiment.

In this subsection I analyze whether using the theoretical equilibrium strategy is still optimal when subjects face opponents that might not play according to equilibrium. To study this question I disaggregate the data to classify subjects according to their individual strategies. Doing this allows us to better understand the types of subjects that compose the sample and how the distribution of types varies across the different treatments. Given these distributions of potential opponents, the task is to assess whether or not the subjects who play according to the theoretical equilibrium receive higher payoffs than the other types.

We can distinguish five types of subjects in the data. The first one corresponds to those subjects who take into account the informative signals, disregard the uninformative ones, and play the game according to the theoretical equilibrium strategy, as in table 6. Recall that the predictions for Country 2 in table 6 correspond to the equilibrium strategies in Country 2 that arise assuming that agents in Country 1 played according to equilibrium. However, subjects that participated in sessions corresponding to Country 1 do not play according to the equilibrium strategies. Given the observed behavior of subjects in Country 1 sessions (see table 7), I construct an empirical equilibrium benchmark for agents in Country 2 that corresponds to the equilibrium strategies that would arise if all agents in Country 2 believed that agents in Country 1 behaved exactly as they did in the experiment. Notice that these equilibrium strategies will differ from the theoretical equilibrium strategies from table 6 only for the treatments where the states are highly correlated \((s \in \{3/4, 1\})\) and the signal about the behavior of agents in Country 1 is informative \((\alpha \in \{3/4, 1\})\), since beliefs about the behavior of agents in Country 1 matter only when the social learning channel is switched on. Table 14 in the appendix contains these empirical equilibrium strategies for each treatment. The second type of subjects in the sample are those who play the game according to this empirical equilibrium. The third type of subjects takes into account the correct information but does not choose actions according to either of these two types of equilibria. The fourth type of subject takes into consideration uninformative signals or fails to take into account informative ones (they exhibit one of the information biases studied in hypothesis 1) and
thus does not behave in accordance with any equilibrium.\footnote{Note that when subjects do not choose the correct information set (i.e. when they exhibit one of the aforementioned biases) it is not possible to analyze the “correct” use of that information by comparing the type of strategies arising from those biased information sets with respect to any type of benchmark or theoretical equilibrium strategy where the same information set is taken into account, since no theoretical benchmark would prescribe subjects to use those signals when forming a strategy.} Finally, subjects of the fifth type behave randomly. Subjects are classified in one of the first four groups by looking at the sequence of choices made for each combination of signals over the last 20 rounds of the experiment. 3 deviations are allowed for each subject.

Table 12 presents, for each treatment, the frequency distributions of these types of subjects and the mean realized payoff of the subjects in each group in the last 20 rounds of the experiment. I analyze payoffs across these groups by making pairwise comparisons between the mean realized payoffs that arise from the equilibrium strategy and the payoffs corresponding to each of the other types to determine if, given the distribution of subjects in each treatment, the equilibrium strategy yields the highest payoffs.\footnote{This is the type of comparison made for all treatments, except for the ones corresponding to the last two columns of table 12 where equilibrium strategies vary with the realization of signal $y$. In these two cases we make comparisons with respect to two benchmarks: the theoretical equilibrium and the empirical equilibrium. Notice in table 12 that the empirical equilibrium coincides with the theoretical equilibrium for all the other treatments. However, for the cases in the last two columns of table 11 no individual strategy in the data coincided with the theoretical equilibrium strategy, therefore, the first comparison is made between the mean realized payoffs for non-equilibrium strategies and the mean expected payoffs that would have arisen if all subjects had followed the theoretical equilibrium strategy, given the state and signal realizations in those treatments. For this reason, we write (e) to denote expected payoffs. The second comparison is made with respect to the empirical equilibrium strategies and the level of significance is captured by the number of asterisks (or lack thereof) in parentheses.}

As is clear from table 12, there is a lot of heterogeneity in individual strategies within each treatment (see El-Gamal and Grether, 1995, for a discussion of the observed heterogeneity of behavioral strategies across subjects and the difficulties to find one unifying theory to explain behavior). We can see from this table that there are four treatments where the subjects that use the theoretical equilibrium strategy exhibit significantly higher payoffs than those who do not. Notice that in these treatments the mean payoffs of subjects who take into account the correct information set but do not use the equilibrium strategy are not statistically different from the payoffs of subjects who exhibit a bias in terms of the information they collect. In these treatments the distributions of types are very different, so we cannot generalize that playing equilibrium yields a higher payoff given a specific distribution of types since this distribution seems to depend on the treatment.

It is interesting to notice that there are no subjects who follow the theoretical equilibrium actions for the treatments where agents have a pessimistic prior, states are correlated and the signal about behavior in Country 1 is informative ($ (s, \alpha) \in \{(3/4, 3/4), (1, 1)\}$). Likewise, we observe a small fraction of subjects who act according to the empirical equilibrium strategy in these treatments. For these two cases I compare the mean realized payoffs of subjects to the mean payoff that would arise if all subjects played according to equilibrium and to the mean payoff corresponding to those subjects that use the empirical equilibrium strategy. For one of these cases, where $s = 3/4$ and $\alpha = 3/4$, we see that the expected payoff from playing the equilibrium strategy is statistically lower than the payoffs realized by subjects who either take
<table>
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<th>Pessimistic prior</th>
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<tr>
<td>Equilibrium</td>
<td>15%</td>
<td>16.67%</td>
<td>25%</td>
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<tr>
<td>Mean payoff</td>
<td>10.4</td>
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<td>Equilibrium (empirical)</td>
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<tr>
<td>Mean payoff</td>
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<td>-</td>
<td>-</td>
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<td>Correct info, non-eq</td>
<td>65%</td>
<td>54.16%</td>
<td>54.16%</td>
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<td>20%</td>
<td>25%</td>
<td>16.67%</td>
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<tr>
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<td>12.5***</td>
<td>11.95</td>
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<td>Mean payoff</td>
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<td>12.6*</td>
<td>7.2***</td>
</tr>
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* significant at 10%; ** significant at 5%; *** significant at 1%; statistical difference with respect to equilibrium payoffs

Table 12: Individual strategies, by treatment
into account the correct information but do not behave according to the theoretical or the empirical equilibrium strategies and those who take into account the incorrect information. However, the payoffs of these two groups are not statistically different from the mean payoffs of the subjects who follow the empirical equilibrium strategies.

To summarize the main points extracted from table 12 we can say that there are significant gains in terms of payoffs from taking into consideration the correct information set and following the theoretical equilibrium strategy in some cases, but not in all. However, in those cases where there is a significant loss in terms of payoffs when subjects depart from the equilibrium predictions, the loss is similar when subjects exhibit a bias in information gathering (by paying attention to the uninformative social learning signal) to the loss of subjects who hold the correct information set but fail to use this information in the way prescribed by the theory (or by the empirical equilibrium strategy). In this sense, we can conclude that neither of these departures seems to be more pervasive than the other in terms of payoffs. With regards to policy implications, this result indicates that in order to maximize agents’ payoffs and reduce the number of defaults, it is not enough to ensure that agents hold the correct information, but it is necessary to make sure that they use this information correctly, otherwise the cost of misusing correct information is not different from the cost of holding the incorrect information in the first place.

5 Relation to the literature

The results of this paper are related to different topics in the literature: theoretical and experimental papers on financial contagion, global games, social learning, and behavioral biases. Given the vast literature in each of these topics, it would be unrealistic to attempt to do a full literature review of the studies related to this paper. For this reason, I will focus on the studies that have a close relationship with the theoretical and experimental setup presented in the paper.

Claessens and Forbes (2001) compile a series of papers that study the contagious episodes in the 1990’s to understand the different channels that could have been responsible for contagion. In the presence of such a plethora of channels, in this paper I have focused on two broad classes that encompass the specific channels studied in the literature. Kaminsky et al (2003) emphasize the importance of these two channels by referring to models of investor behavior based on social learning and models of financial links due to capital flows or common investors. One example of a paper that studies financial links is Kodres and Pritsker (2002), where the severity of contagion is shown to depend on the strength of financial links and on the level of asymmetry of information, and it is shown that contagion can occur even in the absence of public news that would coordinate agents’ decisions. On the other hand, Calvo and Mendoza (2000) present a model of financial contagion through global portfolio diversification where they focus on the social learning channel by modeling contagion as a result of herding behavior. Due to short-selling constraints, the globalization of financial markets weakens the incentives of agents to costly remove the uncertainty about the asset’s return, and instead strengthens the incentives to imitate arbitrary market portfolios. This herding behavior results in financial contagion.

These two papers illustrate the emergence of contagion through the fundamental and the
social learning channel, respectively, in a context where agents are fully rational. Even the herding decision of agents in Calvo and Mendoza (2000) is consistent with the rationality of agents. Pritsker (2001) comments on these issues and suggests that the inability to pin down the exact channels of contagion is not related to irrational contagion, and that in order to explain certain episodes of contagion one needs to find “new” channels through the real economy or the financial sector that would explain contagion. However, the experimental results of section 5 show that in many cases agents overreact to information in a way that is not consistent with rationality, which illustrates “irrational” contagion. The idea of Pritsker (2001) would be desirable from a theoretical point of view but, as this and other studies have shown, behavioral biases are systematically found in many types of financial decisions, which points towards the necessity of acknowledging such biases and explicitly study the way in which agents respond to information.\footnote{For a discussion about incorporating behavioral economics into the study of financial models see Thaler (1999).}

There are some experimental papers that study financial contagion. However, to the author’s knowledge, there are no other papers that study experimentally financial contagion with the use of global games. Cipriani, Gardenal and Guarino (2013) study experimentally a similar setup to Kodres and Pritsker (2002) and find strong contagion effects that support the theoretical model, thus finding evidence for cross-market contagion through fundamental links. They find that as the asymmetries of information are reduced, the transmission of shocks increases. In contrast, the experimental analysis of the present study does not find a higher incidence of contagion when information becomes more precise. However, as observed in section 5, in the present study the social learning bias plays an important role in determining the decisions of subjects, and this channel is not present in the environment studied by Cipriani et al (2013), which could explain the discrepancies. A study that finds evidence of contagion due to social learning is Cipriani and Guarino (2008), where informational cascades lead to financial contagion in an asset market, and these cascades push the price of the asset away from fundamentals.

These two experimental papers find evidence of fundamental and social learning based contagion, respectively. They make assumptions about one specific channel to study and provide evidence for it as a mechanism of contagion. Unlike these papers, the focus of the present study is to understand the relationship of these two different channels as the sources of contagion. In a similar spirit to the present study, two papers study experimentally bank run contagions where the strength of the fundamental links is a treatment variable. Chakravarty, Fonseca and Kaplan (2013) and Brown, Trautmann and Vlahu (2013) study two modified Diamond and Dybvig (1983) setups where two banks are either linked through fundamentals, in which case the states in both banks are identical, or where they are independent.\footnote{The Diamond and Dybvig (1983) setup is characterized by multiple equilibria. Also, agents within a bank are heterogeneous in their preferences for liquidity (early vs late). By using global games to model the economy, the present paper studies a model with a unique equilibrium that allows us to study comparative statics, moreover, in this model agents have the same liquidity preferences.} In both papers, subjects only observe the actions of agents in the first bank before making a decision, so they do not receive any information about the state in their own bank. These two papers are different from each other in that Chakravarty et al (2013) is a dynamic game
where the state of the bank depends on the state in the previous period, and they stay closer to the Diamond and Dybvig (1983) framework by inducing heterogeneous liquidity preferences across subjects. Brown et al (2013), on the contrary, focus on a one shot game where subjects have the same preferences. The evidence from these papers is inconclusive. While Chakravarty et al (2013) find that contagion occurs when the banks are linked and when they are independent, Brown et al (2013) find evidence of contagion only when the banks are linked. Given the structure of these experiments, it is hard to draw conclusions about the way in which subjects use the information at their disposal. There are important differences between these two studies and the present paper, especially in the way in which the treatments are designed to analyze the effect (and interdependence) of the two channels of contagion through the information given to subjects. First, these two papers only vary the strength of the fundamental channel in their treatments, from no correlation to perfect correlation. Second, the information related to the behavior of agents in the first market is always perfect in these two studies, and does not constitute a treatment variable. Finally, subjects in these two studies do not receive any private information about the state in their own bank. The present paper, on the other hand, by varying the strength of the fundamental and the social learning channels of contagion and by endowing subjects with a private signal about the state in their own country, presents clear predictions about the treatments where each of these channels should be at work or not and enough variability across treatments to study these predictions (see hypothesis 1 in section 5). As was shown in section 5, analyzing the way in which subjects respond to the different pieces of information is crucial to understanding the real strength of the channels of contagion. Moreover, the use given by subjects to the different pieces of information is sensitive to the specific combination of the correlation of states, precision of the social learning signal, and prior beliefs.

By studying the social learning channel of contagion the present paper is also related to the literature on social learning in non-contagion contexts. However, the environment presented in this paper is different from the type of environment modeled in the classic models of social learning (see Banerjee, 1992, and Bikhchandani, Hirshleifer and Welch, 1992 for theoretical papers and Anderson and Holt, 1997, for an experimental study). In these papers agents make decisions sequentially and it is shown that after observing a sequence of individual decisions, it is rational for agents to disregard their own private information and follow the actions of the other agents. In the present paper, however, agents do not make individual decisions sequentially, instead, agents in each country make decisions simultaneously and countries become active sequentially.

Weizsacker (2010) performs a meta study of various experiments on social learning, showing that subjects tend to put too much weight on their private signal in situations where it would be rational to herd, according to the empirically optimal action. This analysis, however, is not based on a theoretical decision model that prescribes how agents should act optimally, thus not providing a clear way to characterize departures in terms of specific biases.

In most social learning studies, however, agents normally observe all the decisions of their predecessors. In an experimental setting Celen and Kariv (2005) relax this perfect observation of the history of decisions and study social learning in a context where agents can only observe the action of their immediate predecessor. They find less instances of
herding under imperfect information than under perfect information, even less than the theoretical predictions. They conclude that this behavior could be explained by a “complex multilateral mixture of bounded rationality and limits to the rationality of others” [14], but that it cannot be explained by a generalized Bayesian model that explains the behavior of subjects under perfect information. The Celen and Kariv (2005) conclusion can be related to the present study if we compare the results of the experiment in those treatments where subjects observe the signal about the behavior of agents in Country 1 with noise ($\alpha < 1$) to the treatments where this signal is perfectly precise ($\alpha = 1$). Recall from table 8 that we observe the fundamental and/or the social learning bias in all treatments but the one corresponding to perfectly informative signals. These results, together with the observations of Celen and Kariv (2005), point at the positive relationship between the level of uncertainty in the environment and the emergence of behavioral anomalies.

In terms of the type of information observed by agents in social learning experiments, Celen, Kariv and Schotter (2010) study an environment similar to that of Celen and Kariv (2005), but where subjects can choose whether to observe the actions of their immediate predecessor or to receive her advice about which action to take. In equilibrium these two options are informationally equivalent, however, subjects in the experiment seem to follow the advice given to them by their predecessor more than to copy their action, which increases subjects’ welfare.

In a similar spirit to that of Celen et al (2010), but focusing on sources of information that are more closely related to the ones used in the present study, Duffy, Hopkins and Kornienko (2013) and Goeree and Yariv (2007) analyze the way in which subjects choose to learn about the state in a social learning experiment. Duffy et al (2013) ask subjects to choose between a private signal about the state and a public signal about the actions of their predecessors. They find support for rationality by showing no particular bias towards private or social information. On the other hand, subjects in Goeree and Yariv (2007) choose between observing an informative private signal about the state and a history of play of predecessors who have not chosen a private signal. The latter is clearly an uninformative social signal, which could be analogous to the social learning signal in the present study for the treatments where this signal is unrelated to the payoff relevant state for subjects. The results of Goeree and Yariv (2007) show that one third of subjects choose the uninformative signal and follow it about 90% of the times. The authors identify this behavior as conformity, defined as an intrinsic taste to follow others. The approach taken by these two papers is a natural extension to the present study to disentangle the reasons for the social learning bias observed in the data. Subjects either fail to realize that the information is not useful, which would point at possible cognitive constraints, or they realize that this information is not relevant for them, but still use it for their decisions. This last possibility could be related to the findings of Goeree and Yariv (2007), or to the intrinsic difficulty of ignoring information that is at the subjects’ disposal, even if this information is not relevant. Studying this phenomenon could be an interesting extension for future research.

In terms of global games models that study financial contagion, Dasgupta (2004) and Goldstein and Pauzner (2004) first proved the emergence of financial contagion in equilibrium in a model of global games. The context and channels of financial contagion studied in these two papers are very different. While Dasgupta (2004) focuses on bank run contagion by
carefully modelling the inter-bank linkages, Goldstein and Pauzner (2004) focus on a wealth channel that leads to contagion through the effects that the outcome in the first market has on the level of risk aversion of agents, who participate in both markets. These two papers, however, do not aim at investigating which type of channel gives rise to contagion, instead, they assume a specific channel and prove their results accordingly. Recent theoretical papers that study financial contagion in a global games context are Manz (2010), Oh (2013) and Anhert and Bertsch (2013), who focus on specific channels that drive their modelling decisions.

Finally, the present paper is related to experiments on global games. Heinemann, Nagel and Ockenfels (2004) first took the model of Morris and Shin (1998) to the laboratory and reported evidence of the global games strategies in the data. Other examples of global games experiments include Heinemann et al (2007), who study strategic uncertainty in a global games experiment, and Szkup and Trevino (2013) who study costly information acquisition in a global games context. Overall, the experimental evidence supports the type of strategies prescribed by global games (threshold strategies), but finds a non-trivial relationship between the specific level of the threshold and the amount of uncertainty in the environment.

6 Conclusions

This paper presented the results of an experiment designed to understand the effects of fundamental links and social learning as mechanisms of financial contagion using a global games model as a theoretical benchmark.

While the theory provides very clear predictions about when each of these channels should influence contagion, the experimental results show interesting departures from these predictions. Subjects do not extract information optimally, which leads to two systematic biases related to each of these channels. One is a base rate neglect bias, by which subjects underweight the information contained in the prior about the fundamental in the other country, in cases with high fundamental correlation. This bias weakens the effect of the fundamental channel. The second is an overreaction bias to the signal about the behavior of agents in a foreign country, even in the cases where this signal is uninformative, thus strengthening the social learning channel. These two biases have been documented in the behavioral and experimental literature on individual decision making. The results of this paper find evidence for the emergence of these biases in a strategic context and, more importantly, these biases are found to play an important role in the mechanism of these two channels of contagion. Therefore, these results tie well-known findings in behavioral economics to macroeconomic phenomena.

The emergence of these biases has significant effects in terms of welfare. The way in which agents overreact to the information related to social learning illustrates these effects. In most cases, subjects overreact to the social learning signal by following panics, even in cases where these observations are uninformative. These “irrational” contagious panics lead to welfare losses, with respect to the equilibrium predictions. However, in specific cases, subjects overreact to the social learning signal by following actions that show confidence, which enhances coordination and leads to welfare gains.
In sum, one can construct environments where fundamentals and/or social learning should theoretically lead to financial contagion. However, the results of this paper highlight the importance of understanding the way in which agents process the information related to these channels to better understand the mechanism through which they operate. In many cases, information processing might not conform to the rational or Bayesian paradigm of the models. Characterizing these departures in terms of systematic biases provides a useful way to incorporate behavioral findings into new models of financial contagion.

References


7 Appendix
<table>
<thead>
<tr>
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<th>7</th>
<th>8</th>
<th>9</th>
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<td>$x_i^1$</td>
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<td>3.957***</td>
<td>3.987***</td>
<td>3.249***</td>
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<td></td>
<td>(0.412)</td>
<td>(0.41)</td>
<td>(0.412)</td>
<td>(0.369)</td>
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<td>$y_{roll}$</td>
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<td>(0.291)</td>
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<td>(0 opt, 1 pess)</td>
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<td>(0.971)</td>
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Clustered (by subject) standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 13: Logit estimates of information taken into account for individual actions, by treatment
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<th>Treatment</th>
<th>Induced prior</th>
<th>Correlation of states (s)</th>
<th>Precision of y (alpha)</th>
<th>Equilibrium actions</th>
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<td>C2: 1</td>
<td>Optimistic</td>
<td>Uninformative (1/3)</td>
<td>Uninformative (1/3)</td>
<td>Roll over for all signals</td>
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<td>Optimistic</td>
<td>High (3/4)</td>
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<td>High (3/4)</td>
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<td>Perfect (1)</td>
<td>Roll over for all signals</td>
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<td>Uninformative (1/3)</td>
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<td>C2: 7</td>
<td>Pessimistic</td>
<td>High (3/4)</td>
<td>Uninformative (1/3)</td>
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<td>C2: 8</td>
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<td>High (3/4)</td>
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<td>C2: 9</td>
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<td>High (3/4)</td>
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<td>Perfect (1)</td>
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Table 14: "Empirical" equilibrium predictions for Country 2, given observed behavior in Country 1