Channels of Financial Contagion: Theory and Experiments

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Abstract

Two main classes of channels have been studied as informational sources of financial contagion. One is a fundamental channel that is based on real and financial links, while the second one is a social learning channel that arises as a consequence of noisy observations about the behavior of agents in foreign markets. I model an environment where these two channels are present using global games and test its predictions experimentally in an effort to distinguish the relative strength of these two channels as determinants of subjects' behavior. While the theory makes clear statements about which channels 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 in the data: 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 behavior they observe in a foreign country, i.e. on the social learning channel. The impact of these biases depends on the environment of the economy, which is defined by the parameters in the experimental treatment. These results have important consequences in terms of welfare and provide a characterization of the conditions in the economy that can potentially 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

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1 Introduction

Financial globalization has given rise to an increase in the number of financial crises that are rapidly transmitted across countries – financial contagion (see Schmukler et al, 2006). The crises in Greece and Cyprus and the unraveling 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 these contagious episodes, as well as those occurring after the crises originating 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 possible channels studied in the literature, we can distinguish two main classes of channels: 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). We can define the fundamental channel as encompassing real or financial links, thus characterizing contagion as emerging between countries whose fundamentals are correlated due to, for example, trade partnerships, or from sharing financial linkages, such as common creditors. On the other hand, contagious episodes have also been characterized as the transmission of a crisis between countries that might not have any clear fundamental links but that share certain external characteristics that make investors fear and speculate about the possibility of a crisis in one country, after observing a crisis in a similar market. Under this view, financial contagion arises due to social learning, where investors act according to beliefs about the apparent similarity between markets that then become self-fulfilling and lead to the eventual unfolding of a crisis in the second country in a very short period of time, even in situations where such a crisis could have been avoided. In both of these cases speculation is exacerbated due to 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, since the former is based on existing correlation of fundamentals and the latter is based on observational learning, which leads agents to make inferences from the actions of others that might or might not be relevant to them. 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. Notice, however, that these two types of channels are not mutually exclusive.

This paper studies theoretically and experimentally the effects and interaction of fundamental links and information flows related to social learning on the propagation of a crisis through financial contagion. I develop a theoretical model of financial contagion based on

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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 1900’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, even if this is not in accordance with the theoretical models.
global games that is then tested experimentally with the purpose of providing some empirical
evidence about the strength and interaction of 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 characterize the strength of each
of these two channels.

As pointed out by Goldstein (2012), differentiating between these two channels is crucial
for policy analysis. However, there is no conclusive empirical evidence on the matter. Al-
though a large empirical literature has established a strong link between contagious episodes
and fundamentals (see, for example, Caramazza et al, 2004, or Kaminsky et al, 2004), not
all episodes of contagion can be explained by fundamental links. Many studies focus on the
role of panics derived from social learning that lead to contagion, but the empirical evidence
of this channel has fallen short due to the difficulty for researchers to draw inferences from
the available data.\textsuperscript{3} This can be due to the fact that it is very difficult to measure exactly
how agents react to different sources of information when this specific information is not
available to the econometrician. In this sense, the laboratory is an ideal tool to answer this
type of questions since it provides a natural environment to study the reaction of agents
to different types of information, while controlling and varying the strength of fundamental
links and the accuracy of the information that subjects observe about the behavior of other
agents in a foreign market. Clearly, an experimental session cannot recreate exactly the same
situation that investors in financial markets face. 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 markets 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 they have to make inferences about the realization of the
state and about the likely actions of others in order to make a decision. 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
where agents choose the risky action (say, roll over a loan) if they observe a signal higher than
a certain threshold, and they take the safe action (say, withdraw their funds) if they observe
a signal lower than this threshold. 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. The characterization of
the information structure in global games is not only realistic but also very easily applicable
to many important economic contexts, such as speculative attacks, investment decisions, or
even political revolts. Morris and Shin (1998) first applied this modeling technique to a
speculative attack game of currency crisis where agents have to decide whether to attack the

\textsuperscript{3}Some 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.
currency or not, depending on their beliefs about the likelihood of a devaluation.4

In this paper I apply the techniques of global games to the context of financial contagion by studying the interaction between two economies whose fundamentals are correlated (e.g. countries in the European Union) and they 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. This is a sequential model where agents in the first country make their decisions based only on their prior information and on private signals about the state of the economy, and in a later period agents in the second country get to observe, in addition to the prior and the private signals about the state in their own country, a signal about the behavior of creditors in the first country. Therefore, 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 advantages. 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.

The use of global games to model financial contagion was initially studied by Dasgupta (2004) and Goldstein and Pauzner (2004). However, these studies differ from the current paper, not only because they focus on specific mechanisms of contagion (capital connections of banks in the former, investors’ wealth in the latter), but more importantly because their purpose is different. These two studies, while choosing very different setups, demonstrate that contagion can be an equilibrium outcome in a global game and characterize its effects in the economy. Therefore, we can think of these papers as setting the theoretical ground to study new questions about the forces behind financial contagion with the use of global games.

In this paper, my aim is to characterize the extent and magnitude of fundamental links and social learning as determinants of individual behavior, and how this behavior leads to contagion in the different economic environments. Therefore, the purpose of the experimental analysis is not just to test a theoretical model, but to understand the channels through which financial contagion is more likely to occur. The behavior of agents in financial crises is not always rational and the experimental analysis will allow me to characterize the environments that are more likely to lead to behavioral biases in the way subjects use the information related to each of these two channels.

I first solve the theoretical model with a continuum of agents and continuous distributions of states and signals to understand the main forces and tensions of the model in terms of the channels of contagion. Then I discretize the model in order to implement it experimentally.

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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 these channels and the induced prior to design ten experimental treatments that characterize ten very different environments in the economy. The reason to construct so many treatments is to allow for enough variability in the theoretical predictions about the usefulness of the different sources of information. I study how subjects respond to these different environments by analyzing how they use the information related to each of these channels.

The experimental results revolve around two main hypotheses. The first one relates to how subjects use the information available to them, i.e. I first study whether they identify the signals that are informative for their decision or not. Identifying the informative signals is a way to understand 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 only if the states are correlated. In other words, the fundamental channel should be “switched on” only when the two 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, i.e. they should switch on the social learning channel, 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. Therefore, from a theoretical point of view, a necessary condition to switch on the social learning channel of contagion is that the fundamental channel is also switched on.

For the experiment, the theory prescribes very clearly the treatments in which subjects should switch on or off each of these channels. However, 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, i.e. they put less weight on the fundamental channel in the cases where it should have a stronger 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 the cases where this signal is uninformative. This signal is 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 way in which these biases arise will depend on the conditions of the economy.

The second main hypothesis tested relates to welfare. Due to the two biases found in the data, it is not surprising to see departures between the observed frequencies of withdrawals and those prescribed by equilibrium. We see higher frequencies of withdrawals than those...
prescribed by equilibrium in all but two treatments. As a consequence of such departures, in those treatments with higher frequencies of withdrawals there are significant losses in terms of 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 for subjects in the experiment. 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. To do this, I study the instances where subjects follow the action taken by others when the theory prescribes them to take the opposite action, for the set of signals observed. These correspond to the instances where the equilibrium strategy prescribes that subjects roll over (withdraw) for the set of signals received, but instead subjects choose to withdraw (roll over) if they observe a signal about agents in the first country withdrawing (rolling over). 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 is a clear illustration of the pervasive effects of the social learning channel of contagion and serves as evidence of 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 we observe a significant number of instances where 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 choose to roll over after observing a signal of agents in a foreign country showing confidence in their own market, i.e. we observe evidence of contagious confidence. This departure from equilibrium leads to welfare gains as a consequence of more successful coordination. Not surprisingly, these two treatments exhibit significantly lower frequencies of withdrawals than those prescribed by equilibrium and even than those corresponding to the first best allocation of the social planner.

After studying these departures, we look at the comparative statics results related to the two channels of contagion and find some compliance with the theoretical predictions, but also some departures. These departures are then reconciled with the behavioral findings established in the analysis of the two aforementioned hypotheses.

As an additional result, I 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. 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 with a continuum of agents. I characterize equilibrium and study comparative statics to understand what are the key parameters that determine theoretically the way in which the strength of fundamental links and social learning variables affect the probability of contagion. In section 3 I discretize the environment to implement the model in the laboratory. While keeping the main tensions and forces 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. Section 4 presents the experimental design and the set of parameters used in the experiment. The experimental results are presented in section 5. Section 6 provides a discussion of the results and relates the findings of the paper to the existing literature. Finally, section 7 concludes.

2 The model with a continuum of agents in each country

There are two countries in the economy, for simplicity called Country 1 and Country 2, and a continuum of agents (creditors) in each country, \( i_n \in [0, 1], n = 1, 2 \). The actions of the model take place in two different periods, and agents related to country \( n = 1, 2 \) are active only in period \( n \). Initially, nature chooses the order in which countries become “active”. To simplify the setup, I assume that countries become active in the order of their numeraire, i.e. Country 1 becomes active first, followed by Country 2, and the participants in each country know the order in which countries will become active.

Both countries use standard debt contracts to finance their debt. In each country, a continuum of creditors face an interim stage in their contract where they receive noisy signals about the state of fundamentals and have to decide whether to roll over their loan to maturity or to withdraw their funds at this interim stage. Creditors from country \( n \) have funds invested in country \( n \) and country \( n \) only, \( n = 1, 2 \). Even if the country is solvent, creditors might want to withdraw their funds at the interim stage if they fear that the country is in a vulnerable position and will not repay its debt, and if they fear that other creditors might do the same. These fears are self-fulfilling since countries are more likely to default if creditors withdraw their funds simultaneously.

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.

The two countries are linked through fundamentals (e.g. the European Union), 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. To model this 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 follow 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 normal distribution from which \( \theta_2 \) is drawn, i.e. \( \theta_2|\theta_1 \sim N(\theta_1, \tau_{\theta_2}^{-1}) \). The parameter \( \tau_{\theta_2} \) can thus be interpreted as a measure of the correlation between fundamentals in the two countries, i.e. a measure of fundamental links.

2.1 Actions and payoffs

In each country, separately, a continuum of creditors buy securities to finance the country’s government debt. The way in which these decisions are modeled in each individual country
follows closely the setup of Morris and Shin (2004). The financing is undertaken via a standard debt contract. We assume two different face values, depending on the time of liquidation. The face value of repayment at maturity is 1 and each creditor who rolls over her loan receives this full amount if the country stays solvent. If the country defaults, then creditors who rolled over their investment get zero. At an interim stage, creditors have the opportunity to review their investment. If they choose to withdraw their funds at this interim stage they get the lower face value of early withdrawal $\lambda_n \in (0, 1)$.

Whether Country $n$ stays solvent and honors its debt at maturity or defaults depends on two factors: the underlying state of the economy, $\theta_n$, and the degree of disruption created by early liquidation by creditors. Let $l_n$ be the proportion of withdrawing agents in country $n = 1, 2$. The outcome for Country $n$ at maturity will be determined by comparing the state to the number of withdrawing creditors:

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

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.

Therefore, 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>1</td>
</tr>
</tbody>
</table>
| Withdraw             | $\lambda_n$ | $\lambda_n$

where $\lambda_n \in (0, 1)$ is the premature liquidation value.

If agents knew $\theta_n$ they would act as follows: If $\theta_n > 1$, it would be optimal to roll over their debt, irrespective of the actions of others (in this case, rolling over always yields the high face value $1 > \lambda_n$). If $\theta_n < 0$, 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 $\theta_n \in (0, 1)$ 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, agents do not observe $\theta_n$ directly, but receive noisy private and public signals about it.

### 2.2 Information structure and equilibrium

Recall that fundamentals in both countries are given by

$$
\theta_1 \sim N(\mu_\theta, \tau_{\theta_1}^{-1}) \\
\theta_2 \mid \theta_1 \sim N(\theta_1, \tau_{\theta_2}^{-1})
$$

This information is common knowledge to all agents in both countries.

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5Two 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 these face values are endogenously determined.
2.2.1 Country 1

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

$$x_i^1 \sim N(\theta_1, \tau_1^{-1})$$

where $x_i^1$ are $iid$ across $i \in [0, 1]$ and are independent of $\theta_1$ and $\theta_2$. Based on their prior beliefs and on their private signals, creditors in Country 1 update their beliefs so that

$$\theta_1 | x_i^1 \sim N\left( \frac{\tau_{\theta_1} \mu_\theta + \tau_1 x_i^1}{\tau_{\theta_1} + \tau_1}, (\tau_{\theta_1} + \tau_1)^{-1} \right)$$

Notice that the game in Country 1 corresponds to a standard static global game with public and private signals. We can interpret the prior distribution of $\theta_1$ as a public signal that reflects the level of fundamentals in Country 1 in the previous period, which determines the expectations of agents. The precision of the prior $\tau_{\theta_1}$ thus reflects the stability of Country 1, in the sense that if the economy is stable (high $\tau_{\theta_1}$), then fundamentals in Country 1 would have small variations across periods.

I solve the game in Country 1 using the usual techniques of global games (see Morris and Shin, 2003, Hellwig, 2002, or Morris and Shin, 2004, for details).

I focus on monotone strategies to solve for equilibrium in both countries. In particular, it is shown that there is a unique equilibrium in threshold strategies for each country such that agents in Country $n$ roll over their loan if and only if they observe a private signal higher than a threshold, $x^*_n$, $n = 1, 2$, which depends on the information structure in each country. This threshold value corresponds to the marginal signal that makes agents in Country $n$ indifferent between withdrawing their investment or rolling it over. So the action rule followed by investors in Country $n = 1, 2$ is given by:

$$a_n(x_i^n, \Omega_n) = \left\{ \begin{array}{ll} 
\text{Withdraw if } x_i^n < x^*_n(\Omega_n) \\
\text{Roll over if } x_i^n \geq x^*_n(\Omega_n) 
\end{array} \right.$$

Where $\Omega_n$ is the set of noise parameters that determine the equilibrium threshold in each country. For Country 1 $\Omega_1 = \{\tau_{\theta_1}, \tau_1\}$ and for Country 2 $\Omega_2 = \{\tau_{\theta_1}, \tau_1, \eta, \tau_{\theta_2}, \tau_2\}$, which is explained in detail in the following subsection.

2.2.2 Country 2

In Country 2 the structure of signals is more complex. Just like in Country 1, agents in Country 2 observe private signals about the state in their own country, $\theta_2$, given by $x_i^2 \sim N(\theta_2, \tau_2^{-1})$, where $x_i^2$ are $iid$. Recall that $\theta_2 \sim N(\theta_1, \tau_{\theta_2}^{-1})$. In addition, agents in Country 2 also 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 \( l_1 = \Pr(x_1^* < x_1) = \Phi \left( \frac{x_1^* - \theta_1}{\tau_1^{1/2}} \right) \) is the proportion of creditors in Country 1 that withdraw their funds.\(^6\)

For agents in Country 2 the information updating process is less straightforward than for agents in Country 1. First notice that \( y \sim N \left( \frac{x_1^* - \theta_1}{\tau_1^{1/2}}, \eta^{-1} \right) \), which is equivalent to \( y = \frac{x_1^* - \theta_1}{\tau_1^{1/2}} + \eta^{-1/2} \xi_y \), where \( \xi_y \sim N(0,1) \). Since agents in Country 2 care about \( \theta_1 \) only because it is the mean of the distribution from which \( \theta_2 \) is drawn, \( y \) can be reinterpreted as a public signal about \( \theta_1 \), i.e. \( \theta_1 = x_1^* - \tau_1^{-1/2} y + (\tau_1 \eta)^{-1/2} \xi_y \). 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 that agents in Country 1 hold, which is \( \theta_1 \sim N(\mu_{\theta_1}, \tau_{\theta_1}^{-1}) \). Therefore, the posterior belief that agents in Country 2 hold about \( \theta_1 \), given that they observe signal \( y \) about the proportion of withdrawing agents in Country 1, is given by

\[
\tilde{\theta}_1 = E_2(\theta_1|y) = \frac{\tau_{\theta_1} \mu_{\theta} + \tilde{\eta} \tilde{y}}{\tau_{\theta_1} + \tilde{\eta}}
\]

where \( \tilde{y} = x_1^* - \tau_1^{-1/2} y \) and \( \tilde{\eta} = \tau_1 \eta \). This is equivalent to saying that for agents in Country 2, \( \theta_1|y \sim N \left( \frac{\tau_{\theta_1} \mu_{\theta} + \tilde{\eta} \tilde{y}}{\tau_{\theta_1} + \tilde{\eta}}, (\tau_{\theta_1} + \tilde{\eta})^{-1} \right) \). Notice that \( \frac{d\tilde{y}}{dy} < 0 \), so that \( \frac{d\tilde{\eta}}{dy} < 0 \), which implies that when agents in Country 2 observe a signal that implies a high proportion of agents in Country 1 that have withdrawn their funds, they will update their beliefs about the state in Country 1 downwards. We can interpret \( \tilde{\theta}_1 \) as a composed public signal or “posterior” about \( \theta_1 \) for agents in Country 2 that determines their beliefs over the distribution from which \( \theta_2 \) is drawn. In other words, \( \tilde{\theta}_1 \) is the updated expected mean of the distribution of \( \theta_2 \). Now we analyze how this affects the beliefs about \( \theta_2 \), which is the payoff relevant state for agents in Country 2.

Remember that \( \theta_2 \sim N(\theta_1, \tau_{\theta_2}^{-1}) \), or \( \theta_2 = \theta_1 + \tau_{\theta_2}^{-1/2} \zeta \), where \( \zeta \sim N(0,1) \). What the “posterior” about \( \theta_1 \) is telling us is that \( \theta_1 = \frac{\tau_{\theta_1} \mu_{\theta} + \tilde{\eta} \tilde{y}}{\tau_{\theta_1} + \tilde{\eta}} + (\tau_{\theta_1} + \tilde{\eta})^{-1/2} \tilde{\zeta} \), where \( \tilde{\zeta} \sim N(0,1) \) and \( \zeta \) and \( \tilde{\zeta} \) are independent. Substituting this expression, we can write \( \theta_2 \) in the following way:

\[
\theta_2 = \frac{\tau_{\theta_1} \mu_{\theta} + \tilde{\eta} \tilde{y}}{\tau_{\theta_1} + \tilde{\eta}} + (\tau_{\theta_1} + \tilde{\eta})^{-1/2} \tilde{\zeta} + \tau_{\theta_2}^{-1/2} \zeta
\]

By properties of the Normal distribution, linear combinations of independent Normal random variables follow a Normal distribution as well, so we can define \( \theta_2|y \sim N \left( \frac{\tau_{\theta_1} \mu_{\theta} + \tilde{\eta} \tilde{y}}{\tau_{\theta_1} + \tilde{\eta}}, \tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1} \right) \), or \( \theta_2|y \sim N \left( \tilde{\theta}_1, \tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1} \right) \). This is effectively the “updated” distribution that agents in Country 2 hold about their payoff relevant state \( \theta_2 \).

Taking all of this into consideration, once agents in Country 2 observe their private signals

\(^6\)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).
about $\theta_2$, $x^i_2 \sim N(\theta_2, \tau_2^{-1})$, their posterior belief about $\theta_2$ is given by

$$E_2(\theta_2|x^i_2, y) = \tilde{x}_2 = \frac{(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1})^{-1} \tilde{\theta}_1 + \tau_2 x^i_2}{(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1})^{-1} + \tau_2}$$

i.e. $\theta_2|x^i_2, y \sim N\left( \tilde{x}_2, \left( (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1})^{-1} + \tau_2 \right)^{-1} \right)$.

In this setup there are different ways in which the outcome in Country 1 affects the beliefs of agents in Country 2. The first one is through the signal about the proportion of agents that withdraw their funds in Country 1, $y$, which implies that as $y$ increases, the posterior belief about $\theta_2$ decreases, i.e. a signal about a higher proportion of agents that withdraw their funds in Country 1 leads agents in Country 2 to believe that the fundamentals in Country 2 are weaker, because the fundamentals of both countries are positively correlated. This signal incorporates a component of social learning in the model 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 of information transmitted between Countries 1 and 2, i.e. the quality of information that agents in Country 2 get about events in Country 1. Therefore, $y$ and $\eta$ represent a 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. For this reason, we refer to this as the social learning channel of contagion. Finally, the parameter that ultimately determines how relevant it is for agents in Country 2 to pay attention to the information related to Country 1, i.e. the prior beliefs 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, which is captured by $\tau_{\theta_2}$. This parameter measures purely a fundamental link between countries.$^7$

Therefore, we can summarize the key variables for investigating the two channels of contagion as $\tau_{\theta_2}$, which reflects fundamental ties and natural co-movement between countries, and $\{y, \eta\}$, which illustrates the social learning channel characterized by noisy observations about the behavior of agents in the first country. In particular, $\eta$ is the key parameter for this channel since it measures the accuracy of the signal about the actions taken by agents in Country 1. If $\eta$ is not very large (precise) then $y$ is not very informative for agents in Country 2. Thus, for it to be rational for agents in Country 2 to take the behavior of agents in Country 1 into account, both $\eta$ and $\tau_{\theta_2}$ need to be relatively high, i.e. the countries need

---

$^7$There are additional effects from parameters relevant to Country 1 that affect actions of agents in Country 2, such as the precision of private signals in Country 1, $\tau_1$ (i.e. the level of transparency of Country 1 with its own citizens), or the precision of the distribution from which $\theta_1$ is drawn, $\tau_{\theta_1}$. If we think of the mean of the prior $\mu_0$ as reflecting the realized level of fundamentals in Country 1 in a previous period, then $\tau_{\theta_1}$ could reflect the stability of Country 1, in the sense that fundamentals in a very stable country would have small variations across periods (high $\tau_{\theta_1}$). In general, we assume a low $\tau_{\theta_1}$, so that there is enough uncertainty and instability in the economy to make the problem interesting. These effects are taken into account in the “posterior prior” about $\theta_2$ and are secondary effects for studying the two channels of of contagion that we are interested in.
to have a significant correlation and the information received about the behavior of agents in Country 1 should not be too noisy.

The effects of these two channels on the probability of contagion are analyzed theoretically in section 2.4 of comparative statics, but it is the experimental results in section 5 that will provide a better insight to understand the effect of each of these channels on the emergence of contagion. As will be explained later, the effects of these channels on the probability of contagion will depend on the prior beliefs about the state in Country 1 (optimistic vs pessimistic prior). We can interpret the mean of the prior $\mu_0$ as a public signal that reflects the level of fundamentals in the past, thus determining the expectations of agents.

2.3 Equilibrium characterization

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. We solve the two subgames separately and then turn our attention to the effects that the outcome in Country 1 has on the outcome in Country 2.

2.3.1 Country 1

Since this setup corresponds to a standard global game, it is easily established that there is a unique equilibrium in monotone strategies such that agents in Country 1 roll over their loan to maturity if and only if they observe a signal higher than a threshold $x_1^*$, which depends on the parameters of the model. This threshold value corresponds to the marginal signal that makes agents in Country 1 indifferent between rolling over their loan and withdrawing their funds.

Define the posterior value for which creditors are indifferent between taking both actions as

$$\tilde{x}_1^* = \frac{\tau_1 \mu_0 + \tau_1 x_1^*}{\tau_1 + \tau_1}$$

Or equivalently, if they observe the signal:

$$x_1^* = \frac{\tau_1 \mu_0}{\tau_1} + \frac{\tau_1 \mu_0}{\tau_1} x_1^* - \frac{\tau_1 \mu_0}{\tau_1}$$

(1)

Notice that there is a positive and linear relationship between the optimal signal threshold $x_1^*$ and the optimal posterior threshold $\tilde{x}_1^*$. For this reason and for ease in exposition we will refer to the optimal posterior threshold when talking about optimal threshold strategies, unless otherwise specified.

**Critical Mass condition.** The critical value of fundamentals at which Country 1 is indifferent between defaulting and honoring its debt is when $\theta_1 = l_1$, where $l_1$ is the proportion of creditors who withdraw their funds in Country 1 as a result from the switching strategy.
around $x_1^*$. Let $\theta_1^*$ be the critical state at which this happens, i.e. $\theta_1^* = l_1$. The incidence of withdrawals is given by the mass of creditors that receive a signal below the threshold $x_1^*$, i.e. $l_1 = \Pr(x_1 < x_1^*) = \Phi\left(\sqrt{\tau_1}(x_1^* - \theta_1^*)\right)$. Since $\theta_1^* = l_1$, then the Critical Mass condition (CM) is given by:

$$
\theta_1^* = \Phi\left(\sqrt{\tau_1}(x_1^* - \theta_1^*)\right) = \Phi\left(\frac{\tau \theta_1}{\tau_1} \left(\tilde{x}_1^* - \mu_\theta + (\tilde{x}_1^* - \theta_1^*)\right)\right)
$$

\begin{equation}
\text{(2)}
\end{equation}

**Payoff Indifference condition.** At the switching point, a creditor is indifferent between rolling over her loan and withdrawing her funds. The payoff of early withdrawal is the low face value $\lambda_1$, and the expected payoff of rolling over the loan is equal to the probability that the country stays solvent (since this payoff is normalized to 1), which happens whenever $\theta_1 > \theta_1^*$. Since the conditional density over $\theta_1$ has mean $\tilde{x}_1^*$ and precision $\tau_{\theta_1} + \tau_1$, the Payoff Indifference (PI) condition is given by:

$$
\frac{\Pr(\theta_1 > \theta_1^*|x_1^*)}{1 - \Phi\left(\sqrt{\tau_{\theta_1} + \tau_1} (\theta_1^* - \tilde{x}_1^*)\right)} = \lambda_1
$$

\begin{equation}
\text{(3)}
\end{equation}

which implies

$$
\theta_1^* - \tilde{x}_1^* = \frac{\Phi^{-1}(1 - \lambda_1)}{\sqrt{\tau_{\theta_1} + \tau_1}}
$$

\begin{equation}
\text{(4)}
\end{equation}

or

$$
\tilde{x}_1^* = \theta_1^* - \frac{\Phi^{-1}(1 - \lambda_1)}{\sqrt{\tau_{\theta_1} + \tau_1}}
$$

\begin{equation}
\text{(5)}
\end{equation}

**Equilibrium in Country 1.** For equilibrium, we need to solve simultaneously equations 2 and 4. In order to have a unique equilibrium, there needs to be a unique pair of $(\tilde{x}_1^*, \theta_1^*)$ that solves these equations simultaneously. Substituting $\tilde{x}_1^*$ in equation 2 and solving for $\theta_1^*$:

$$
\theta_1^* = \Phi\left(\frac{\tau \theta_1}{\tau_1} \left(\theta_1^* - \mu_\theta - \Phi^{-1}(1 - \lambda_1) \left(\frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}}\right)\right)\right)
$$

\begin{equation}
\text{(6)}
\end{equation}

To ensure a unique solution for $\theta_1^*$, the right hand side of equation 6 needs to have a slope smaller than one everywhere. As has been shown in the global games literature (see Hellwig, 2002, Morris and Shin, 2003), this is achieved by imposing certain restrictions on the noise parameters. In particular, the slope of the right hand side of equation 6 needs to be less than 1, i.e. $\frac{\tau \theta_1}{\sqrt{\tau_1}} \phi\left(\frac{\tau \theta_1}{\sqrt{\tau_1}} \left(\theta_1^* - \mu_\theta - \Phi^{-1}(1 - \lambda_1) \left(\frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}}\right)\right)\right) < 1$. Since $\phi(\cdot) \leq \frac{1}{\sqrt{2\pi}}$ everywhere, then it is sufficient to impose that $\frac{\sqrt{\tau}}{\tau_{\theta_1}} > \frac{1}{\sqrt{2\pi}}$. This effectively means that private signals need to be precise enough with respect to the precision of the prior.
Substituting the resulting equilibrium $\theta_1^*$ in 5 the equilibrium posterior cutoff is:

$$\tilde{x}_1^* = \Phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta_1^* - \mu_\theta - \Phi^{-1} (1 - \lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) - \Phi^{-1} (1 - \lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \tag{7}$$

Notice that in equilibrium the probability that an agent observes a signal lower than threshold $x_1^*$ is equal to $\Pr(x_1^* < x_1^*)$ and corresponds to the proportion of agents that withdraw their funds, which we have called $l_1 = \Pr(x_1^* < x_1^*) = \Phi \left( \frac{x_1^* - \theta_1}{\tau_{\theta_1}^{1/\tau_1}} \right)$.

In a similar setup to the present paper but where contagion is not a possibility, 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 $\mu_\theta$).

I now solve for equilibrium in Country 2 and analyze how the outcome in Country 1 affects the outcome in Country 2.

### 2.3.2 Country 2

I solve for equilibrium in Country 2 in a similar fashion as in Country 1 in the sense that it is a static global game. The difference is that now one needs to take into account the fact that agents in Country 2 also receive a public signal about the fraction of agents in Country 1 that withdraw their funds. This information serves as an additional signal about the state of the economy in Country 1, which gives agents in Country 2 more information about the mean of the distribution from which their payoff-relevant state, $\theta_2$, is drawn.

Once agents in Country 2 observe the public signal about the proportion of agents that withdraw their money in Country 1 and their own private signals about $\theta_2$, $x_2^i \sim N(\theta_2, \tau_2^{-1})$, their posterior belief about $\theta_2$ is given by

$$E_2(\theta_2|x_2^i, y) = \tilde{x}_2^i = \frac{\left( \frac{1}{\tau_{\theta_2}^{1/\tau_2}} + (\tau_{\theta_2} + \tilde{\eta})^{-1} \right)^{-1} \tilde{\theta}_2 + \tau_2 x_2^i}{\left( \frac{1}{\tau_{\theta_2}^{1/\tau_2}} + (\tau_{\theta_2} + \tilde{\eta})^{-1} \right)^{-1} + \tau_2} \tag{8}$$

i.e. $\theta_2|x_2^i, y \sim N\left( \frac{\left( \frac{1}{\tau_{\theta_2}^{1/\tau_2}} + (\tau_{\theta_2} + \tilde{\eta})^{-1} \right)^{-1} \tilde{\theta}_2 + \tau_2 x_2^i}{\left( \frac{1}{\tau_{\theta_2}^{1/\tau_2}} + (\tau_{\theta_2} + \tilde{\eta})^{-1} \right)^{-1} + \tau_2}, \left( \frac{1}{\tau_{\theta_2}^{1/\tau_2}} + (\tau_{\theta_2} + \tilde{\eta})^{-1} \right)^{-1} + \tau_2 \right)$.

Just as for Country 1, I prove that there is a unique equilibrium in monotone strategies such that agents in Country 2 roll over their loan to maturity if and only if they observe a signal higher than a threshold $x_2^*$, which corresponds to the marginal signal that makes agents in Country 2 indifferent between taking either action.

The posterior value for which creditors are indifferent between withdrawing their money or rolling over the loan until maturity is given by:

$$\tilde{x}_2^* = \frac{\left( \frac{1}{\tau_{\theta_2}} + (\tau_{\theta_2} + \tilde{\eta})^{-1} \right)^{-1} \tilde{\theta}_2 + \tau_2 x_2^*}{\left( \frac{1}{\tau_{\theta_2}} + (\tau_{\theta_2} + \tilde{\eta})^{-1} \right)^{-1} + \tau_2} \tag{9}$$
Or equivalently, if they observe the signal:

\[ x_2^* = \left[ \frac{(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}{\tau_2} \right] \bar{x}_2^* = \frac{(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1}}{\tau_2} \bar{\theta}_1 \]

where \( \bar{\theta}_1 = \frac{\tau_{\theta_1} \mu_0 + \hat{\eta} \bar{y}}{\tau_{\theta_1} + \hat{\eta}} \), \( \bar{y} = x_1^* - \tau_1^{-1/2} y \), and \( \hat{\eta} = \tau_1 \eta \).

**Critical Mass condition.** Just as in the case of Country 1, the critical value of fundamentals at which Country 2 is indifferent between being solvent and defaulting is when \( \theta_2 = l_2 \), where \( l_2 \) is the proportion of creditors who withdraw in Country 2 resulting from the switching strategy around \( x_2^* \). Let \( \theta_2^* \) be the critical state at which this happens, i.e. \( \theta_2^* = \frac{\tau_{\theta_1} \mu_0 + \hat{\eta} \bar{y}}{\tau_{\theta_1} + \hat{\eta}} \). The proportion of agents that withdraw their funds is given by the mass of creditors that receive a signal below the threshold \( x_2^* \), i.e. \( l_2 = \Pr(x_2 < x_2^*) = \Phi \left( \sqrt{\tau_2 (x_2^* - \theta_2^*)} \right) \). Since \( \theta_2^* = l_2 \), then the Critical Mass condition for Country 2 (CM) is:

\[ \theta_2^* = \Phi \left( \sqrt{\tau_2 (x_2^* - \theta_2^*)} \right) = \Phi \left( \sqrt{\tau_2 \left( \frac{(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}{\tau_2} \right)} \right) \]

\[ \left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}{\tau_2} \right) \]

\[ = \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}{\tau_2} \left( \bar{x}_2^* - \hat{\theta}_1 \right) + (\hat{x}_2^* - \theta_2^*) \]

\[ (11) \]

**Payoff Indifference condition.** At the switching point, a creditor is indifferent between taking either action. The payoff of early withdrawal is \( \lambda_2 \), and the expected payoff of rolling over is the probability that the country honors its debt, which happens whenever \( \theta_2 > \theta_2^* \). Since the conditional density over \( \theta_2 \) has mean \( \hat{x}_2 = \frac{(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}{\tau_2} \) and precision \( (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2 \), the Payoff Indifference (PI) condition for Country 2 is given by:

\[ 1 - \Phi \left( \sqrt{\tau_2 (x_2^* - \theta_2^*)} \right) = \lambda_2 \]

which implies

\[ \theta_2^* - \hat{x}_2^* = \frac{\Phi^{-1} \left( 1 - \lambda_2 \right)}{\sqrt{(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}} \]

\[ (13) \]

or

\[ \hat{x}_2^* = \theta_2^* - \frac{\Phi^{-1} \left( 1 - \lambda_2 \right)}{\sqrt{(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}} \]

\[ (14) \]
Equilibrium in Country 2. To solve for equilibrium, from equations 11 and 12 I solve for \( \theta_2^* \) and \( \tilde{x}_2^* \) simultaneously. Substituting equation 14 into the CM condition we get:

\[
\theta_2^* = \Phi \left( \frac{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1}}{\sqrt{\tau_2}} \left( \theta_2^* - \tilde{\theta}_1 - \frac{\sqrt{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1} + \tau_2 \Phi^{-1} (1 - \lambda_2)}}{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1}} \right) \right) \tag{15}
\]

In order to ensure a unique solution for \( \theta_2^* \), the right hand side of equation 15 needs to have a slope smaller than one everywhere. A sufficient condition for this to happen is to set

\[
\phi \left( \frac{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1}}{\sqrt{\tau_2}} \left( \theta_2^* - \tilde{\theta}_1 - \frac{\sqrt{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1} + \tau_2 \Phi^{-1} (1 - \lambda_2)}}{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1}} \right) \right) < 1
\]

Since \( \phi(\cdot) \leq \frac{1}{\sqrt{2\pi}} \), then it is sufficient to impose that \( \frac{\sqrt{\tau_2}}{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1}} \rightarrow \frac{1}{\sqrt{2\pi}} \). Intuitively this condition has a similar interpretation as in the case of Country 1, since it requires the precision of private signals, \( \tau_2 \), to be higher than the precision of the public information that is composed by the information that agents in Country 2 possess about Country 1 (i.e. the precision of the prior about \( \theta_1 \), \( \tau_{\theta_1} \), the precision of private signals in Country 1, \( \tau_1 \), and the precision of the public signal they receive about the proportion of agents who withdraw their money in Country 1, \( \eta \)). In particular, it is important to note that this is not just a technical requirement, but that it has a natural interpretation in terms of the model. For example, since the public signal \( y \) creates social learning, an increased precision of this signal might lead agents to rationally overreact to it and lead to multiplicity of equilibria. Therefore, in order to ensure uniqueness, we need all the components of the variance of the composed public signal to be not too precise.

Substituting the resulting equilibrium \( \theta_2^* \) in 14 we get the equilibrium posterior cutoff:

\[
\tilde{x}_1^* = \Phi \left( \frac{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1}}{\sqrt{\tau_2}} \left( \theta_2^* - \tilde{\theta}_1 - \frac{\sqrt{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1} + \tau_2 \Phi^{-1} (1 - \lambda_2)}}{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1}} \right) \right) - \frac{\Phi^{-1} (1 - \lambda_2)}{\sqrt{\left( \frac{1}{\tau_{\theta_2}} + \left( \frac{1}{\tau_{\theta_1}} + \tilde{\eta} \right)^{-1} \right)^{-1} + \tau_2} \tag{16}
\]

**Definition 1** A pure strategy Perfect Bayesian Nash Equilibrium of the game with two countries, \( n = 1, 2 \), is a decision rule \( a_n(x^n; \Omega_n) \) such that agents in both countries behave optimally:

\[
a_n(x^n; \Omega_n) = \begin{cases} 
\text{Withdraw if } x^n < x^n^*(x^n; \Omega_n) \\
\text{Roll over if } x^n \geq x^n^*(x^n; \Omega_n)
\end{cases}
\]
where
\[
\begin{align*}
    x_1^* (x_1^1; \Omega_1) &= \frac{\tau_{\theta_1} + \tau_1}{\tau_1} \theta_1^* - \frac{\tau_{\theta_1}}{\tau_1} \mu_\theta - \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_1} \Phi^{-1} (1 - \lambda_1) \\
    x_2^* (x_2^1; \Omega_2) &= \left[ \left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1}}{\tau_2} \right)^{-1} + \tau_2 \right] \theta_2^* - \left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1}}{\tau_2} \right)^{-1} \tilde{\theta}_2 \\
    &\quad - \frac{\sqrt{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1}}}{\tau_2} \Phi^{-1} (1 - \lambda_2)
\end{align*}
\]
and \(\theta_n^*\) solve:
\[
\begin{align*}
    \theta_1^* &= \Phi \left( \sqrt{\frac{\tau_1}{\tau_{\theta_1}}} \left( \frac{\tau_{\theta_1}}{\tau_1} (\tilde{x}_1^* - \mu_\theta) + (\tilde{x}_1^* - \theta_1^*) \right) \right) \\
    \theta_2^* &= \Phi \left( \sqrt{\frac{\tau_2}{\tau_{\theta_2}}} \left( \frac{\tau_{\theta_2}}{\tau_2} (\tilde{x}_2^* - \tilde{\theta}_1) + (\tilde{x}_2^* - \theta_2^*) \right) \right)
\end{align*}
\]
for \(\tilde{x}_1^* = \frac{r_{\theta_1} \mu_\theta + r_{\theta_1} x_1^1}{r_{\theta_1} + r_{\theta_1}}, \tilde{x}_2^* = \frac{(r_{\theta_2}^{-1}(r_{\theta_1} + \tilde{\eta})^{-1})^{-1} y_1 + r_{\theta_2} x_2^2}{(r_{\theta_2}^{-1}(r_{\theta_1} + \tilde{\eta})^{-1})^{-1} + r_{\theta_2}}, \tilde{\theta}_1 = \frac{r_{\theta_1} \mu_\theta + \tilde{\eta} y}{r_{\theta_1} + \tilde{\eta}}, \tilde{\theta}_2 = x_1^* - \tau_{\theta_1}^{-1/2} y, \tilde{\eta} = \tau_{\theta_1} \eta, \Omega_1 = \{\tau_{\theta_1}, \tau_1\}, \) and \(\Omega_2 = \{\tau_{\theta_2}, \tau_1, \eta, \tau_{\theta_2}, \tau_2\}.
\]

**Proposition 1** Suppose that
\[
\frac{\sqrt{\tau_1}}{\tau_{\theta_1}} > \frac{1}{\sqrt{2\pi}}
\]
and
\[
\frac{\sqrt{\tau_2}}{\left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tilde{\eta})^{-1}}{\tau_2} \right)^{-1}} > \frac{1}{\sqrt{2\pi}}
\]
hold. Then there is a unique equilibrium of the game with two countries characterized by thresholds \(\{x_1^*, \theta_1^*\}\) and \(\{x_2^*, \theta_2^*\}\).

### 2.3.3 Effect of introducing a signal about the behavior of agents in Country 1 on default in Country 2

The introduction of the public signal about the behavior of creditors in Country 1 illustrates the social learning channel of contagion and, as we will see later on, will play an important role in the experimental results. However, before analyzing these behavioral results, we look at the effect that the introduction of this signal has on the probability of default in Country 2 from a theoretical point of view, keeping all other things equal.

The noisy signal about the behavior of creditors in Country 1 determines the actions of creditors in Country 2 by affecting the posterior beliefs of agents. In general, the information structure in a global game gives rise to a unique equilibrium that is usually inefficient, since in equilibrium defaults might occur due to a problem of illiquidity and not of insolvency. This is the case when a default occurs for fundamentals for which countries could have stayed...
solvent if creditors had not withdrawn their funds. In the model, this is characterized by the threshold level for fundamentals, $\theta_n^*$, being larger than zero, since, in principle, defaults can be avoided as long as $\theta_n > 0$ and agents coordinate their actions on rolling over. However, when $\theta_n^* > 0$ there is a range of fundamentals $\theta_n \in (0, \theta_n^*)$ for which default occurs in equilibrium as a result of agents’ beliefs about the state of the economy and about the beliefs of other agents, which lead them to withdraw their funds, and thus provoke a default.

In this subsection I study the effect that the introduction of $y_i$, the signal about behavior of agents in Country 1, has on the threshold value for fundamentals in Country 2 that determines the range of fundamentals for which the country defaults due to self-fulfilling beliefs. I compare the threshold level that arises when agents in Country 2 receive information about the behavior of agents in Country 1, $\theta_2^*$, to the threshold level that would arise if agents in Country 2 did not get any information about the actions of agents in Country 2. We refer to this threshold as $\tilde{\theta}_2$. In particular, $\tilde{\theta}_2$ is defined as the threshold that would arise if the only information held by agents in Country 2 was be the public information composed by:

$$
\begin{align*}
\theta_1 & \sim N(\mu_\theta, \tau_{\theta_1}^{-1}) \\
\theta_2 & \sim N(\theta_1, \tau_{\theta_2}^{-1})
\end{align*}
$$

And the private signals:

$$
\tilde{x}_2^i \sim N(\theta_2, \tau_2^{-1})
$$

In this case, Bayesian updating would lead agents in Country 2 to believe

$$
\theta_2 | \tilde{x}_2^i \sim N \left( \frac{(\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1})^{-1} \mu_\theta + \tau_2 \tilde{x}_2^i}{(\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1})^{-1} + \tau_2}, \left( (\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1})^{-1} + \tau_2 \right)^{-1} \right)
$$

To find equilibrium, we define the posterior value for which creditors are indifferent between withdrawing their money or rolling over the loan until maturity as:

$$
s^* \frac{x_2}{x_2} = \frac{(\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1})^{-1} \mu_\theta + \tau_2 s^* \tilde{x}_2}{(\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1})^{-1} + \tau_2}
$$

Or equivalently, if they observe the signal:

$$
s^* \tilde{x}_2 = \frac{(\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1})^{-1} + \tau_2}{\tau_2} s^* \tilde{x}_2 - \frac{(\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1})^{-1} \mu_\theta}{\tau_2}
$$

The CM condition is then given by:

$$
\begin{align*}
\tilde{\theta}_2^* &= \Phi \left( \sqrt{\tau_2} (s^* \tilde{x}_2 - \tilde{\theta}_2^*) \right) \\
&= \Phi \left( \sqrt{\tau_2} \left( \frac{(\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1})^{-1}}{\tau_2} (s^* \tilde{x}_2 - \mu_\theta) + (s^* \tilde{x}_2 - \tilde{\theta}_2^*) \right) \right)
\end{align*}
$$

18
And the PI condition is:

\[ 1 - \Phi \left( \sqrt{\left( \tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1} \right)^{-1} + \tau_2 \left( \bar{\theta}_2^* - \bar{x}_2^* \right)} \right) = \lambda_2 \]  

(22)

which implies

\[ \tilde{\theta}_2^* - \tilde{x}_2^* = \frac{\Phi^{-1} (1 - \lambda_2)}{\sqrt{\left( \tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1} \right)^{-1} + \tau_2}} \]  

(23)

or

\[ \tilde{x}_2^* = \tilde{\theta}_2^* - \frac{\Phi^{-1} (1 - \lambda_2)}{\sqrt{\left( \tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1} \right)^{-1} + \tau_2}} \]  

(24)

Putting the CM and PI conditions together and solving for \( \tilde{x}_2^* \) and \( \tilde{\theta}_2^* \) simultaneously to find equilibrium, we get the following condition:

\[ \tilde{\theta}_2^* = \Phi \left( \sqrt{\left( \tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1} \right)^{-1} \left( \tilde{\theta}_2^* - \mu_\theta - \frac{\sqrt{\tau_2 \left( \bar{\theta}_2^* - \bar{x}_2^* \right)}}{\sqrt{\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1}}} \Phi^{-1} (1 - \lambda_2) \right)} \right) \]  

(25)

Similar to the previous cases, in order to ensure a unique equilibrium we assume that

\[ \frac{\sqrt{\tau_2 \left( \bar{\theta}_2^* - \bar{x}_2^* \right)}}{\sqrt{\tau_{\theta_2}^{-1} + \tau_{\theta_1}^{-1}}} > \frac{1}{\sqrt{2\pi}}. \]

To understand the effect that the introduction of the signal about the proportion of withdrawing agents in Country 1, \( y \), has on the probability of default in Country 2, we need to compare \( \theta_2^* \) and \( \tilde{\theta}_2^* \). However, it is not possible to derive conclusive results for a wide range of parameters analytically, so we turn our attention to results based on numerical simulations.\(^8\) I find that the effect of introducing signal \( y \) on the probability of default in Country 2 depends heavily on ex-ante, or prior, beliefs. In particular, if agents have an optimistic prior (high \( \mu_\theta \)), then in general \( \theta_2^* > \tilde{\theta}_2^* \), unless there is a very low realization of \( y \), i.e. if agents have an optimistic prior about the state of the economy, introducing a noisy signal about the behavior of agents in Country 1 will increase the probability of default in Country 2, unless the realization of \( y \) is very low. This means that the introduction of this signal will in general affect beliefs in a way that makes agents more hesitant to roll over and thus reduces the range of states for which Country 2 stays solvent.

On the other hand, if agents in Country 2 have pessimistic prior beliefs about the state of the economy, then \( \theta_2^* < \tilde{\theta}_2^* \), unless there is a very high realization of \( y \). This means that when agents have a pessimistic prior, introducing a signal about the behavior of agents in Country 1 leads to a decrease on the probability of default in Country 2, unless they observe a very high realization of \( y \).

Clearly, the strength of these results depends on the precision of \( y \) (\( \eta \)) and on the correlation between states (\( \tau_{\theta_2} \)). These results are somewhat intuitive and illustrate the disruptive

\(^8\) The algebraic expressions to study these results are lengthy and therefore not included in the appendix. However, they are available from the author by request.
effect that this signal might have on coordination through the beliefs of agents.

As I will show in the next subsection, prior beliefs will also play an important role when analyzing comparative statics.

## 2.4 Comparative statics

We now turn our attention to understand how variations in the strength of the fundamental and social learning channels of contagion affect the probability of contagion across countries. In the first section of the appendix I study the effects that different parameters of the model have on the probability of default of each specific country. These parameters are 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 payoff of early withdrawal, $\lambda_n$, for $n = 1, 2$. These are basic comparative statics results that are usually performed for this type of models and that allow us to better understand the forces in the model and the results about comparative statics with respect to the two channels of contagion, which are the focus of this study.

Below, I present the comparative statics about the specific channels that might lead to contagion, i.e. I study how the probability of default in Country 2 is affected by the correlation between fundamentals and by the information that agents in Country 2 observe about the actions of agents in Country 1. In this section I assume that the conditions for uniqueness of equilibrium hold. All proofs are relegated to the appendix.

I focus on the effect of changes of the parameters of the model on the probability of default in Country 2 measured changes in $\theta_2^*$. In particular, since default occurs for $\theta_2 < \theta_2^*$, an increase in $\theta_2^*$ implies a larger range of values of $\theta_2$ for which Country 2 defaults, i.e. a default in Country 2 is more likely to occur. Likewise, a decrease in $\theta_2^*$ means that the range of values of $\theta_2$ for which Country 2 stays solvent increases, so that default is less likely to occur.

### 2.4.1 The two channels of contagion

We now turn our attention to study the two channels of contagion that have been outlined in the paper. They both have to do -albeit in different ways- with public information held by agents in Country 2. The fundamental channel is characterized by changes in the probability of a default in Country 2 that follow a change in the correlation between the fundamentals of both countries, or the level of fundamental co-movement, which is captured by $\tau_{\theta_2}$. The social learning channel illustrates how the probability of default in Country 2 is affected when agents in Country 2 observe a signal about the proportion of agents that withdraw their funds in Country 1 ($y$) and by the precision of this signal ($\eta$).

The following remark presents the results for the fundamental channel of contagion.

#### Remark 1

1. If the probability of default in Country 2 is low (low $\theta_2^*$) and agents have an optimistic prior about the state of the economy (high $\tilde{\theta}_1$), then a higher correlation between Country 1 and Country 2 (i.e. a higher precision $\tau_{\theta_2}$) will further decrease the probability of default in Country 2.

2. If the probability of default in Country 2 is high (high $\theta_2^*$) and agents have a pessimistic prior about the state of the economy (low $\tilde{\theta}_1$), then a higher correlation between
Country 1 and Country 2 (i.e. a higher precision $\tau_{\theta_2}$) will increase the probability of default in Country 2.

This result has a very intuitive interpretation. What is implicit in this result is that when agents have an optimistic prior about fundamentals in Country 2 they are “ex-post” optimistic about fundamentals in Country 1, since the states are correlated and the beliefs about fundamentals in Country 2 are composed by the prior beliefs about the state in Country 1 and the signal that agents in Country 2 observe about the proportion of agents that withdraw in Country 1. Therefore, when agents in Country 2 hold an optimistic prior about the state in Country 2 they implicitly believe that the realized state in Country 1 was good, so 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. 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 result clearly illustrates the mechanism for contagion arising from the fundamental channel. Remark 1 effectively means that a higher correlation between fundamentals in both countries implies that the outcome in Country 2 will be highly determined by beliefs about the state in Country 1, i.e. a higher correlation will increase the probability of contagion between countries. This result implies that when agents in Country 2 are pessimistic about the state in Country 1 then a higher correlation between fundamentals will increase the probability of financial contagion, which is detrimental for the economy in Country 2. However, there is also a positive effect of such a correlation, since, in the presence of optimistic beliefs, an increase in fundamental correlation leads to a “positive contagion” by decreasing the probability of default in Country 2.

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.

The result in the next remark is intuitive and highlights the effect of $y$ on contagion by showing that a higher probability of default in Country 2 results when agents in Country 2 receive a signal about a higher proportion of agents in Country 1 withdrawing their funds.

**Remark 2** A higher signal about the proportion of agents that withdraw their funds in Country 1, $y$, increases the probability of default in Country 2.

This could be thought of as a first order effect of the social learning channel of contagion since it is related to the effect of the magnitude of the signal about the actions of the agents in Country 1 on the events in Country 2. To investigate this point further, I investigate how this effect is determined by the precision of $y$, $\eta$, by taking the second derivative $\frac{d^2\theta_2}{dy}$. However, due to the lack of an analytical characterization, I use numerical simulations to understand this result.\(^9\) Numerical simulations suggest that the effect of $y$ on the probability

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\(^9\)The analytical derivation for this result is lengthy and thus it is not included in the appendix, but it is available by request to the author.
of default in Country 2, characterized by $\theta_2^*$, will be stronger as the precision of $y$, measured by $\eta$, increases, for most parameter values. The only situation where the opposite effect is found is when $\mu_{\theta_2}$ is very high and $y$ is even higher. This, however, is an unlikely scenario since, as we have established, a higher $\mu_{\theta_2}$ leads to a lower probability of agents in Country 1 withdrawing their money, i.e. to a lower $x_1^*$. This, in turn, implies that agents in Country 2 will in general observe signals about the proportion of agents that withdraw their funds in Country 1 of lower magnitude, i.e. they will observe low realizations of $y$. However, there is a non-zero probability of this type of situation occurring (i.e. a high $\mu_{\theta_2}$ accompanied by an even higher $y$) since the support of the normal distribution of $y$ is infinite. This could also happen, for example, if the variance of the distribution of $y$ is very large so that the signal $y$ is so noisy that even if the proportion of agents in Country 1 who withdraw is low, agents in Country 2 might observe a very high $y$.

Effect of an increase in $\eta$ on the probability of default in Country 2. To analyze the other path of the social learning channel of contagion, we take a step back 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 $\theta_2$, denoted by $(\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tau_{1,\eta})^{-1})^{-1}$. Therefore, just like $\tau_{\theta_2}$, the effect arising from changes in $\eta$ on the probability of default, $\theta_2^*$, will depend on whether “prior” 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 (or posterior) mean of the distribution of $\theta_2$, denoted by $\hat{\theta}_1 = \frac{\tau_{\theta_2} \mu_{\theta} + \eta y}{\tau_{\theta_2} + \eta}$, which determines whether beliefs are optimistic or pessimistic. This means that there are two effects that might not go in the same direction. 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 effect an “information effect” since it changes the level of the expected or posterior mean of the distribution of $\theta_2$, thus affecting the type of beliefs held by agents. Therefore, an increase in the precision $\eta$ will, on the one hand, be driven to have a similar impact on $\theta_2^*$ as an increase in $\tau_{\theta_2}$ (i.e. it will either increase or decrease the probability of default depending on whether agents have a pessimistic or an optimistic prior about $\theta_2$), but the final effect will actually depend on how $\eta$ affects this pessimism or optimism of agents through its impact on $\hat{\theta}_1$. So variations 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. This implies that, in certain cases, an increase in $\eta$ might lead ex-ante beliefs to switch from optimism to pessimism (or vice versa), which would have very different implications on the probability of default in Country 2. In the first section of the appendix I develop the expression for this result, however, it is not possible to draw conclusions analytically from the expression of the derivative of $\theta_2^*$ with respect to $\eta$ in an intuitive way. Numerical results indicate that if prior beliefs about $\theta_1$ are pessimistic (low $\mu_{\theta_1}$), then an increase in $\eta$ leads to a decrease in the probability of default in Country 2 if $y$ is low, since an increase in the precision of a low $y$
makes agents more optimistic, or to an increase in the probability of default in Country 2 if $y$ is high, since an increase in the precision of a high $y$ confirms the agents’ pessimism. On the other hand, if agents have an optimistic prior about $\theta_1$ (high $\mu_\theta$) then an increase in $\eta$ leads to an increase in the probability of default in Country 2, since a positive proportion of withdrawals is always bad news, so an increase in the precision of this signal makes agents more pessimistic. As we can see, the information effect seems to be strong enough that, in some cases, it provokes agents to switch from being optimistic to pessimistic (or vice versa). The precise magnitude of this effect depends on the parameters of the model.

We have so far characterized financial contagion in a global games model with a continuum of agents to understand 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.

With this in hand, we move on to the experimental implementation of the model. To do so, I simplify the setup by discretizing the number of players, the state space, and the signal space, but keeping all the important tensions of the model, with the intention to simplify the environment for experimental subjects. The objective of the experimental exercise is to better understand and disentangle the path through which the different parameters that characterize the fundamental and social learning channels of contagion actually lead agents to change their behavior, and to add another important element that might play a role in contagious episodes, which is behavioral biases in the use of information. The laboratory offers an ideal environment to study the interaction between these forces by allowing to study, in a controlled environment, the decisions of real agents when being given information that is perfectly observable by the researcher. In particular, it provides an easy way for the researcher to understand how agents take into consideration different pieces of information and then translate this information into actions, which is something that is not possible to observe with available data on financial crises.

3 Discrete model

The second part of this study is to take the theoretical model of financial contagion to the laboratory and explore experimentally how subjects adjust their behavior to variations in the parameters corresponding to the two channels of contagion, and what consequences this might have in terms of welfare.

In this section, I discretize the model of section 2 with the intention of simplifying the environment in order to make it as clear as possible to the experimental subjects. For this reason, the model implemented in the laboratory has a discrete number of agents and discrete state and signal spaces that characterize the state of the economy qualitatively as being low, medium, or high.
In each Country \( n = 1, 2 \), there are 2 players. The state \( \theta_n \) can be either low, medium, or high, \( \theta_n \in \{ L_n, M_n, H_n \} \). I simplify the setup while keeping all the important elements that are crucial for the analysis. For example, to keep the structure of a global game, we assume a lower and upper dominance region for states \( L_n \) and \( H_n \), and an intermediate region, \( M_n \), where agents need to coordinate on rolling over in order for the country to stay solvent.

Just as in the continuous model, in each country \( n = 1, 2 \) agents make a binary choice \( a_n^i \in \{ 0, 1 \} = \{ \text{withdraw, roll over} \} \). In the experiment, we refer to these two possible actions as \( \{ B, A \} \), respectively, to avoid framing effects. The payoff from withdrawing (taking action \( B \)) is set to \( \lambda_n \) and the payoff of rolling over (taking action \( A \)) depends on the state of the economy and on the actions of others. If the country stays solvent, then agents that roll over receive a positive constant payoff \( X > \lambda_n \), however, if the country defaults then agents that roll over receive \( 0 \). As mentioned above, to keep the global game structure of the game, I assume that when the state is high \( (\theta_n = H_n) \) the country always stays solvent, i.e. rolling over is a dominant strategy. When the state is low \( (\theta_n = L_n) \) the country always defaults, i.e. withdrawing is a dominant strategy. Finally, 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 figure 1.

<table>
<thead>
<tr>
<th>( \theta_n = L_n )</th>
<th>( A )</th>
<th>( B )</th>
<th>( \theta_n = M_n )</th>
<th>( A )</th>
<th>( B )</th>
<th>( \theta_n = H_n )</th>
<th>( A )</th>
<th>( B )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A )</td>
<td>0, 0</td>
<td>( 0, \lambda_n )</td>
<td>( A )</td>
<td>( X, X )</td>
<td>( 0, \lambda_n )</td>
<td>( A )</td>
<td>( X, X )</td>
<td>( X, \lambda_n )</td>
</tr>
<tr>
<td>( B )</td>
<td>( \lambda_n, 0 )</td>
<td>( \lambda_n, \lambda_n )</td>
<td>( B )</td>
<td>( \lambda_n, 0 )</td>
<td>( \lambda_n, \lambda_n )</td>
<td>( B )</td>
<td>( \lambda_n, X )</td>
<td>( \lambda_n, \lambda_n )</td>
</tr>
</tbody>
</table>

Table 1: Payoffs in the discrete model, Countries 1 and 2

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 give rise to a unique equilibrium.

### 3.1 Country 1

As mentioned above, the state in Country 1 can take one of three values: low, medium, or high, \( \theta_1 \in \{ L_1, M_1, H_1 \} \). The prior (unconditional) distribution for \( \theta_1 \) is characterized by probabilities \( p \) and \( q \): \( \Pr (L_1) = p, \Pr (M_1) = q, \Pr (H_1) = 1 - p - q \). Notice that this prior distribution of \( \theta_1 \) will also characterize the prior beliefs of agents in Country 2, depending on the correlation of the states between the two countries.

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 \( \tau \) 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 \( \theta_1 \in \{L_1, M_1, H_1\} \). We assume that \( r > \frac{1}{3} \) so that the signals and states are positively correlated (i.e. there is a higher probability of observing a signal consistent with the realized state than a signal inconsistent with it).

<table>
<thead>
<tr>
<th></th>
<th>( L_1 )</th>
<th>( M_1 )</th>
<th>( H_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Pr (l_1</td>
<td>\cdot) )</td>
<td>( r )</td>
<td>( \frac{(1-r)}{2} )</td>
</tr>
<tr>
<td>( \Pr (m_1</td>
<td>\cdot) )</td>
<td>( \frac{(1-r)}{2} )</td>
<td>( r )</td>
</tr>
<tr>
<td>( \Pr (h_1</td>
<td>\cdot) )</td>
<td>( \frac{(1-r)}{2} )</td>
<td>( \frac{(1-r)}{2} )</td>
</tr>
</tbody>
</table>

Table 2: Conditional distribution of private signals, Country 1

3.1.1 Equilibrium

For the discrete model the characterization of equilibria in Country 1 will depend on the specific combination of parameters. Although there can potentially be multiple equilibria, I choose parameters for the experiment that ensure a unique equilibrium in monotone strategies, to be consistent with the results from the model with a continuum of agents described in section 2. By restricting our attention to monotone equilibria, agents will have a unique symmetric equilibrium where they will follow one of the 4 possible monotonic strategies: always withdraw \((a^i_1 (x^i_1) = 0, \text{ for all } x^i_1)\), roll over only for high signals \((a^i_1 (x^i_1) = 0 \text{ if } x^i_1 \in \{l_1, m_1\}, a^i_1 (h_1) = 1)\), roll over for low and medium signals \((a^i_1 (l_1) = 0, a^i_1 (x^i_1) = 1 \text{ if } x^i_1 \in \{m_1, h_1\})\), or always roll over \((a^i_1 (x^i_1) = 1, \text{ for all } x^i_1)\). The equilibrium will coincide with one of these four types of strategies depending on the parameters of the model.

3.2 Country 2

Just as in the continuous model, we assume that 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 \( \tau_{\theta_2} \) 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:

<table>
<thead>
<tr>
<th></th>
<th>( L_1 )</th>
<th>( M_1 )</th>
<th>( H_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Pr (L_2</td>
<td>\cdot) )</td>
<td>( s )</td>
<td>( \frac{(1-s)}{2} )</td>
</tr>
<tr>
<td>( \Pr (M_2</td>
<td>\cdot) )</td>
<td>( \frac{(1-s)}{2} )</td>
<td>( s )</td>
</tr>
<tr>
<td>( \Pr (H_2</td>
<td>\cdot) )</td>
<td>( \frac{(1-s)}{2} )</td>
<td>( \frac{(1-s)}{2} )</td>
</tr>
</tbody>
</table>

Table 3: Conditional distribution of the state in Country 2, given the realization of the state in Country 1

This means that \( \Pr (L_2 | L_1) = s \), \( \Pr (L_2 | M_1) = \Pr (L_2 | H_1) = \frac{(1-s)}{2} \), and so on. The parameter \( s \geq 1/3 \) measures 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 affect 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 the game, call \( w \in \{0, 1, 2\} \) the true number of withdrawals in Country 1 and \( y \in \{0, 1, 2\} \) 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 \( \frac{1-\alpha}{2} \). 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, i.e. 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 = 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>
</tr>
<tr>
<td>( \Pr(y = 1</td>
<td>\theta_1, \cdot) )</td>
<td>( \frac{1-\alpha}{2} )</td>
</tr>
<tr>
<td>( \Pr(y = 2</td>
<td>\theta_1, \cdot) )</td>
<td>( \frac{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 \( s > 1/3 \). This information is valuable to them when the states are correlated because it shapes their beliefs about the state in Country 2, \( \theta_2 \), which is their payoff relevant state.

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 \( x_i^2 \in \{l_2, m_2, h_2\} \), given the state \( \theta_2 \) is then analogous to table 2 for Country 1, i.e. \( \Pr(l_2 | L_2) = r \), \( \Pr(l_2 | M_2) = \Pr(l_2 | L_2) = \frac{1-r}{2} \), and so on.

### 3.2.1 Equilibrium

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 \( (x_i^2) \) 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 \( x_i^2 \in \{l_2, m_2, h_2\} \) establishes a higher probability of withdrawing for low signals than for medium, than for high signals:

\[
\Pr(a_i^2 = 0 | l_2, y) \geq \Pr(a_i^2 = 0 | m_2, y) \geq \Pr(a_i^2 = 0 | h_2, y)
\]
where \( a^i_2 = 0 \) corresponds to the case where agent \( i \) chooses to withdraw.

For a given private signal \( x^i_2 \), the monotonicity of actions with respect to the public signal \( y \in \{0, 1, 2\} \) establishes a higher probability of withdrawing after observing 2 agents withdraw, than after observing 1 agent withdraw, than after observing 0 agents withdraw in Country 1:

\[
\Pr \left( a^i_2 = 0 | x^i_2, 2 \right) \geq \Pr \left( a^i_2 = 0 | x^i_2, 1 \right) \geq \Pr \left( a^i_2 = 0 | x^i_2, 0 \right)
\]

The specific ordering of signals in equilibrium, in terms of combinations of \( x^i_2 \) and \( y \), will depend on the parameters chosen.

The procedure of information updating necessary to find the equilibrium of the discrete game is contained in the second section of the appendix.

4 Experimental procedures

4.1 Parameters used in the experiment

For simplicity we assume that the payoff of withdrawing and the payoff of rolling over when the country stays solvent are the same for both countries, i.e. \( \lambda_1 = \lambda_2 = 4 \) and \( X = 20 \), respectively, so the matrices of payoffs, depending on the realization of the state in Country \( n = 1, 2 \), are given in table 5:

<table>
<thead>
<tr>
<th>( \theta_n = L_n )</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A )</td>
<td>0,0</td>
<td>0,4</td>
</tr>
<tr>
<td>( B )</td>
<td>4,0</td>
<td>4,4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \theta_n = M_n )</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A )</td>
<td>20,20</td>
<td>0,4</td>
</tr>
<tr>
<td>( B )</td>
<td>4,0</td>
<td>4,4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \theta_n = H_n )</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A )</td>
<td>20,20</td>
<td>20,4</td>
</tr>
<tr>
<td>( B )</td>
<td>4,20</td>
<td>4,4</td>
</tr>
</tbody>
</table>

Table 5: Payoffs in the experiment, Countries 1 and 2

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 \( \alpha \). We 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”, i.e. 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”, i.e. 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 results presented in section 2, 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 the following:

Finally, the precision of the private signals in each country is determined by \( r = 6/10 \), so that, in Country \( n = 1, 2 \), the probability distribution of observing a private signal, given the realization of the state is given by:
Table 6: Prior probability distributions

<table>
<thead>
<tr>
<th></th>
<th>Optimistic prior</th>
<th>Pessimistic prior</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pr (L₁)</td>
<td>Pr (M₁)</td>
</tr>
<tr>
<td>17.5%</td>
<td>17.5%</td>
<td>65%</td>
</tr>
<tr>
<td>17%</td>
<td>5%</td>
<td>17%</td>
</tr>
<tr>
<td>65%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Conditional distribution of private signals in the experiment, Countries 1 and 2

<table>
<thead>
<tr>
<th></th>
<th>Lₙ</th>
<th>Mₙ</th>
<th>Hₙ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pr (lₙ</td>
<td>.)</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Pr (mₙ</td>
<td>.)</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Pr (hₙ</td>
<td>.)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

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

4.2 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.¹⁰

The design implemented is a between subjects design that allows us 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 ones that determine the strength of each of the channels of contagion analyzed so far, i.e. the correlation between fundamentals (s) and the precision of the signal about the behavior of agents in Country 1 (α). 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 altering the strength of the fundamental and social learning channels. For this reason, every combination of (s, α) 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 6 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 (θ₁) and the number of withdrawals in Country 1, that, depending on the parameters s and α, 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.

¹⁰Instructions can be found in: https://files.nyu.edu/it384/public/instructions_all.pdf
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 present 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.

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, $x_1^i \in \{“low”, “medium”, “high”\}$ 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, $x_2^i \in \{“low”, “medium”, “high”\}$ 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, $x_1^i$, the realized state in Country 1, $\theta_1 \in \{“Low”, “Medium”, “High”\}$, 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 similar 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.$^{11}$

As mentioned earlier, for the Country 2 treatments, in each round, every pair in Country 2 was randomly matched with a different pair from Country 1 in order to generate the state $\theta_2$ and the signal about the behavior of agents in Country 1. Therefore, subjects in Country 2 were explicitly told that, just as they were being matched randomly with a new person every round, they would also observe information about the behavior of a randomly chosen pair that played in a previous session, and that the subjects in that experiment were also randomly matched in pairs from round to round. Subjects in Country 2 were also told in the instructions the precise way in which the state $\theta_2 \in \{“Low”, “Medium”, “High”\}$ 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 the public signal about

$^{11}$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 $B$”.  

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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.

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 8 summarizes the experimental design and contains the equilibrium predictions for each treatment in Country 1 and Country 2.

I investigate the predictions of the theory in terms of the channels of contagion for each set of parameters in the experiment through two main hypotheses. The first one relates to the channels that should be at work in each of these treatments, i.e. depending on the combination of parameters, we can identify which channels should be “switched on” or “switched off”. Through this hypothesis, I study how the individual decisions to roll over or withdraw depend on the information available to subjects that is related to the two channels of contagion. With this information in hand, we turn to the second main hypothesis to analyze how the incidence of withdrawals depends on the way subjects use the available information and how this affects their realized payoffs and the welfare of the economy.

5 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 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 the type of behavior emerging from inducing an optimistic versus a pessimistic prior for these subjects. We then turn our attention to the behavior of subjects in Country 2, which is the focus of this study, by testing two main hypothesis that focus on the role that these channels play in the individual decisions to withdraw or to roll over and their effects in terms of welfare. The study of these hypothesis will shed light on the behavioral sources that determine the “empirical” strength of these channels and thus their consequences in terms of outcomes. I then compare the comparative statics results in the data with the theoretical predictions and reconcile the observed departures with the findings related to the analysis of the two aforementioned hypotheses. As an additional result, 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.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Induced prior</th>
<th>Correlation of states (s)</th>
<th>Precision of y (alpha)</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 8: Equilibrium predictions, for each experimental treatment
Most of the results will be presented for the last 20 rounds played by subjects to allow for behavior to stabilize, unless otherwise specified.

5.1 Country 1

The main question when analyzing sessions related to Country 1 is whether or not we see different behavior when subjects face an optimistic vs a pessimistic prior. We find significant differences in these two treatments. Table 9 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 9: 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.

As a result of these decisions, we also observe a significantly lower rate of default for intermediate states \( (\theta_1 = M_1) \) of 16.67% for the case of an optimistic prior, as opposed to a rate of default of 61.67% for the case of a pessimistic prior.\(^{12}\) These two numbers are different to the 1% level of significance.

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 these two 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 8. 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 8, which assumes that subjects in Country 1 behaved according to equilibrium, and one alternative strategy that corresponds to the best response of subjects in Country 2 to the observed behavior of subjects in Country 1, illustrated in table 9. 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 \( (\alpha > 1/3) \).

\(^{12}\)Note that the relevant state to study rates of default is only the intermediate state where \( \theta_1 = M_1 \), 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 \( (\theta_1 = L_1) \) default always occurs and when the state is high \( (\theta_1 = H_1) \) default never occurs, irrespective of the actions of agents.
5.2 Country 2

I now analyze the behavior of subjects that participated in sessions related to Country 2. The two channels of contagion studied in this paper are closely related to two of the pieces of information received by subjects. Recall that subjects receive three pieces of information or 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 \( (x^i_2 \in \{l_2, m_2, h_2\}) \). Since the private signal \( x^i_2 \in \{l_2, m_2, h_2\} \) is always informative about the state \( \theta_2 \), 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 be taken into account for 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 \( (\alpha > 1/3) \).

Table 10 below summarizes hypothesis 1 by showing, for each treatment, whether subjects should switch “on” or “off” the two channels of contagion, according to the theoretical predictions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Correlation of states</th>
<th>Precision of ( y )</th>
<th>Prior ( (\text{opt vs pess}) )</th>
<th>Public signal ( y )</th>
<th>Private signal ( x^i_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3</td>
<td>1/3</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>3/4</td>
<td>1/3</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>1/3</td>
<td>3/4</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td>3/4</td>
<td>3/4</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
</tr>
</tbody>
</table>

Table 10: Theoretical benchmark of information processing

As we will see in table 11, 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, or Bar-Hillel, 1980, for a review of this bias). 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, 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 11 reports the results of five random
effects logit regressions that test Hypothesis 1. In all the estimations the dependent variable
is the probability to choose the action “roll over”, and the independent variables are the
private signals \( x_{i2}^s \), the public signal about the number of agents who rolled over in Country
1, \( y_{roll} \), a dummy variable \( d_{prior} \) 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 \( x_{i2}^s \) and with the public signal about the proportion of agents that
roll over, \( y_{roll} \). The 5 specifications differ in the combination of \((s, \alpha)\) parameters that define
each treatment (as in table 8). In each of these specifications (each combination of \((s, \alpha)\))
I pool the data from sessions where an optimistic and a pessimistic prior were induced, in
order to estimate whether or not there is a significant difference in behavior under these
two different priors by looking at the coefficient of the dummy \( d_{prior} \). The numbers in bold
indicate departures, in terms of significance, from the expected results, indicating the cases
where the relevant signals were not taken into account or where uninformative signals were
taken into account, i.e. identifying the existence of the biases described above.

From table 11 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 the cases considered.
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 in terms of its
precision \((\alpha > 1/3)\). 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
since it carries no relevant information about the fundamental state in Country 2. Therefore,
we can identify a bias of overreaction to this uninformative signal for cases where the states
are uncorrelated and/or this signal is perfectly imprecise. Notice, however, that the size of
the bias, measured by the magnitude of the coefficient corresponding to \( y_{roll} \), 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 remaining of the paper I will refer to this overreaction
bias as the social learning bias.
The other bias that we can easily identify from the regressions in table 11 is a type of base rate neglect, which is characterized by subjects not taking the information contained in the prior into account for their decision. We identify qualitatively the emergence of this bias by the lack of statistical significance of the coefficients related to the dummy that differentiates the two treatments according to the prior, $d_{\text{prior}}$. Note that, regardless of the informativeness of the signal about the behavior of agents is Country 1, subjects in Country 2 should take the information of their prior into account as long as $s > 1/3$, i.e. as long as the fundamentals are positively correlated. This means that we should see the coefficients related to $d_{\text{prior}}$ 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 $s = 3/4$, 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). For simplicity, in the remaining 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{By saying this we are not ruling 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.}

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$s = 1/3$, $s = 3/4$, $s = 1/3$, $s = 3/4$, $s = 1$, $s = 1/3$, $s = 3/4$, $s = 3/4$, $s = 1$, $s = 1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>1/3</td>
<td>1/3</td>
<td>3/4</td>
<td>3/4</td>
<td>1</td>
</tr>
<tr>
<td>$x_2^s$</td>
<td>3.211***</td>
<td>3.943***</td>
<td>3.973***</td>
<td>3.236***</td>
<td>2.303***</td>
</tr>
<tr>
<td>(0.337)</td>
<td>(0.417)</td>
<td>(0.41)</td>
<td>(0.369)</td>
<td>(0.304)</td>
<td></td>
</tr>
<tr>
<td>$y_{\text{roll}}$</td>
<td>0.646***</td>
<td>0.696***</td>
<td>1.246***</td>
<td>1.876***</td>
<td>1.048***</td>
</tr>
<tr>
<td>(0.215)</td>
<td>(0.254)</td>
<td>(0.871)</td>
<td>(0.291)</td>
<td>(0.32)</td>
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<td>$d_{\text{prior}}$</td>
<td>-0.345</td>
<td>-0.796</td>
<td>-0.224</td>
<td>-0.373</td>
<td>-2.952***</td>
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<td>(0.939)</td>
<td>(0.797)</td>
<td>(0.871)</td>
<td>(0.875)</td>
<td>(0.819)</td>
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<td>$d_{\text{prior}}^* x_i$</td>
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<td>0.222</td>
<td>0.213</td>
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<tr>
<td>(0.49)</td>
<td>(0.501)</td>
<td>(0.49)</td>
<td>(0.493)</td>
<td>(0.385)</td>
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</tr>
<tr>
<td>$d_{\text{prior}}^* y_{\text{roll}}$</td>
<td>0.574**</td>
<td>0.056</td>
<td>0.408</td>
<td>-0.293</td>
<td>1.079***</td>
</tr>
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<td>(0.319)</td>
<td>(0.328)</td>
<td>(0.348)</td>
<td>(0.385)</td>
<td>(0.404)</td>
<td></td>
</tr>
<tr>
<td>$C$</td>
<td>-2.426***</td>
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<td>-3.355***</td>
<td>-2.999***</td>
<td>-1.372**</td>
</tr>
<tr>
<td>(0.665)</td>
<td>(0.593)</td>
<td>(0.661)</td>
<td>(0.633)</td>
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Table 11: Logit estimates of information taken into account for individual actions, by treatment

Clustered (by subject) standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%
If we compare this result to specification 4 where both signals are highly informative, but where some noise still remains, it is interesting to notice that only when there is noise in the observation of signals 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 likelihood of observing this bias as the uncertainty in the environment increases.

It is important to note that the qualitative results presented in table 11 do not change when controlling for risk aversion (see table 15 in the appendix). We see the same biases arise in all the specifications above, and the coefficients related to these biases to be very similar in table 11 and in table 15 in the appendix 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 now turn our attention to the second hypothesis investigated in the experiment about the effects of the observed behavior on welfare. We analyze welfare effects by studying frequencies of withdrawals and realized payoffs. We compare these two measures with two benchmarks, the theoretical equilibrium and the first best allocation (defined by the actions prescribed by a social planner). In particular, we compare the frequencies of withdrawals and the mean realized payoffs in the data with the frequencies of withdrawals and the mean payoffs that would arise if subjects played according to equilibrium, for the realizations of states and signals in the experiment, and to the frequencies of withdrawals and mean payoffs resulting from a social who could enforce the first best allocations.

To determine the frequencies of withdrawals in equilibrium we take the equilibrium predictions for each treatment (see table 8) and calculate the total number of instances where a subject should withdraw, given the realization of states and signals in the experiment, and divide it by the total number of decisions in the last 20 rounds. In other words, the equilibrium frequencies of withdrawals are based on the realization of states and signals in the experiment. Likewise, the frequencies of withdrawals corresponding to the first best depend on the realization of states in the experiment. In particular, the social planner solution would correspond to agents choosing to withdraw when the state is low ($\theta_2 = L_2$) and to roll over when the state of the world is either medium or high ($\theta_2 \in \{M_2, H_2\}$). Different frequencies of withdrawals in the data with respect to these benchmarks would imply departures from equilibrium and/or the first best allocation that might carry welfare consequences related to the observed biases.

**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.

For each treatment, panel A of table 12 compares the observed frequency of withdrawals to the equilibrium predictions and to the predictions corresponding to the first best allocation where a social planner determines the actions that subjects should take to maximize their payoffs, given the realization of the state. The numbers in parentheses below the observed frequencies of withdrawals and to the equilibrium predicted frequencies, correspond
to the proportion of instances where 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 lower the loss in terms of welfare.

As we can see from panel A in table 12, in general we do not find support for Hypothesis 2 in the data, since, 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, notice that when we compare the percentage of observed withdrawals to the percentage of withdrawals that would arise in the data if a social planner could enforce the first best allocations, 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 advice them to do so. However, it does not mean that they are doing so in those situations that the planner would recommend. In fact, subjects in the experiment many times make the wrong decisions, according to the first best benchmark. This is captured by the numbers in parenthesis that correspond to the proportion of withdrawals that coincide with situations in which the social planner would prescribe agents to withdraw. 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 12 contains, for each treatment, the mean realized payoff of subjects in the experiment and the mean realized payoffs that would arise if subjects were to follow the equilibrium strategies and if they were to follow the recommendation of the social planner, for the observed states and signals in the experiment. Similar to what was done in panel A of table 12, the number in parenthesis 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) with respect to mean first best payoffs. These numbers can be thought of as an index of welfare losses in terms of payoffs: the larger the number, the smaller is the loss.

We can see from panel B in table 12 that in all but two cases (pessimistic prior, $s \in \{3/4, 1\}$, $\alpha \in \{3/4, 1\}$) 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 or gains for subjects associated to departures from equilibrium behavior we compare the ratio of realized payoffs to first best payoffs and the ratio of equilibrium payoffs to first best payoffs, i.e. we compare the welfare loss (gain) associated to playing equilibrium to the welfare loss (gain) associated to the observed behavior of subjects. 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
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<td>Optimistic prior</td>
<td>$s = 1/3$ $s = 1/3$ $s = 1/3$ $s = 1/3$ $s = 1/3$</td>
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<tr>
<td>$\alpha = 1/3$</td>
<td>$\alpha = 1/3$</td>
<td>$\alpha = 1/3$</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>$0%<strong>$ $0%</strong><em>$ $0%</em><strong>$ $0%</strong><em>$ $0%</em>**$</td>
<td>$0%<em><strong>$ $0%</strong></em>$ $0%<em><strong>$ $0%</strong></em>$ $0%***$</td>
</tr>
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<td></td>
<td>$- - - - -$</td>
<td>$- - - - -$</td>
</tr>
<tr>
<td>First best</td>
<td>$35%$ $19.17%***$ $27.50%$</td>
<td>$20.42%$ $15%$</td>
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* 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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<td>$s = 1/3$ $s = 1/3$ $s = 1/3$ $s = 1/3$ $s = 1/3$</td>
</tr>
<tr>
<td>$\alpha = 1/3$</td>
<td>$\alpha = 1/3$</td>
<td>$\alpha = 1/3$</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>$13%$ $16.17%<em><strong>$ $14.5%$ $15.92%</strong></em>$ $17%$</td>
<td>$11.9%$ $8%$ $12.32%***$ $7.1%$ $6.37$</td>
</tr>
<tr>
<td></td>
<td>$0.645$ $0.757$ $0.697$ $0.808$</td>
<td>$0.885$</td>
</tr>
<tr>
<td>First best</td>
<td>$14.4%<strong>$ $16.93%</strong>*$ $15.6%**$</td>
<td>$16.73%***$ $17.6%$</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 12: Comparison of rate of withdrawals and mean payoffs to equilibrium and efficiency benchmarks, by treatment
pessimistic prior, high or perfect correlation of states \((s \in \{3/4, 1\})\) and highly or perfectly precise signals about behavior of 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 12 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. In particular, the systematic overreaction to the signal associated to the social learning bias in hypothesis 1 has important implications in terms of outcomes. To measure the cost induced by the social learning bias, in the next subsection I analyze how the signal about the behavior of agents in Country 1 changes subjects’ decisions even in the cases where such signals are uninformative.

5.2.1 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 theoretical equilibrium action for the signals received by the subject imply that she should roll over, and (2) rolling over after observing a signal of agents in Country 1 rolling over, when the equilibrium action for the signals received by the subject imply that she should 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 cases 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, so they withdraw as well. The second case is similar to the first case, except that the signal they observe informs them that exactly both subjects from Country 1 withdrew. Notice that in this case, even if subjects observe a signal of both pair members withdrawing in Country 1, the theoretical equilibrium still would prescribe them to roll over. 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 as well when the equilibrium action would be to withdraw, given the signals that they observe.

Table 13 reports the mean payoffs associated to 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 particular instances. Table 13 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 13 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 of 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 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 to the social learning bias.

It is interesting to notice that exactly 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 12 above. These cases show evidence for contagious confidence, or positive contagion, where subjects chose 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.

In the next subsection we make use of the analysis presented so far about the behavior of subjects and its effect on welfare, and we use it to reconcile the departures from the theory in terms of comparative statics.

### 5.2.2 Comparative statics

When determining whether the observed comparative statics coincide or not with the theoretical predictions, I compare the results of the experiment to the predictions for the discrete model used in the experiment and contained in table 8.

Below I analyze the comparative statics about the effect on the frequency of individual withdrawals that result from changes in (i) the realization of the signal about behavior of agents in Country 1, \(y\), (ii) the correlation of states, \(s\), and (iii) the precision of the signal about behavior in Country 1, \(\alpha\). These are analogous to the comparative statics results presented for the theoretical model with a continuum of agents in section 2.4. I use frequencies of individual decisions to withdraw as a proxy for rates of default in order to use all the observations in the data for the last 20 rounds because focusing on rates of default would only be informative for the cases where the state is medium \(\theta_2 = M_2\), since in the other two cases default is independent of the actions of agents (default always occurs for low states, \(\theta_2 = L_2\), and it never occurs for high states, \(\theta_2 = H_2\)).

The first comparative static result corresponds to the effect of a higher realization of the signal about behavior of agents in Country 1 on the probability of default in Country 2 (analogous to remark 2 from section 2). Given the empirical results presented so far, it is not surprising that the data supports this prediction, i.e. that a signal about a larger number of agents that withdraw in Country 1 leads to higher rates of withdrawals in Country 2. This is the case not only for the treatments where, in equilibrium, the rate of default should increase when subjects observe a higher number of withdrawals in Country 1 (see predictions for treatments C2: 9 and C2:10 in table 8), but also for the other cases where the theory for the discrete model does not prescribe a change in withdrawals arising from
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<td>$\alpha = 1/3$</td>
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<td>16.41</td>
</tr>
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<td>% total decisions</td>
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<td>17.08%</td>
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<tr>
<td>Follow 1 withdraw</td>
<td>$4^{***}$</td>
<td>$4^{***}$</td>
</tr>
<tr>
<td>Eq. (roll over)</td>
<td>13</td>
<td>13.78</td>
</tr>
<tr>
<td>% total decisions</td>
<td>15%</td>
<td>9.38%</td>
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* significant at 10%; ** significant at 5%; *** significant at 1%; statistical difference with respect to the payoff of following equilibrium strategies

Table 13: Cost, in terms of payoffs, of following others, by treatment
different realizations of this signal. This is a direct consequence of the social learning bias by which subjects overreact to the signal about the behavior of agents in Country 1, even if this signal is uninformative.

Given the number of treatments and the variation of parameters, the comparative statics results can vary a lot from treatment to treatment. To more efficiently present these results we consider separately the cases of optimistic and pessimistic priors and study the impact on frequencies of withdrawals of varying either the correlation of states, \( s \), or the precision of the signal about the behavior of agents in Country 1, \( \alpha \). When comparing frequencies of withdrawals I establish statistical significance of pairwise comparisons in the frequencies of withdrawals that can be found in table 12.

**Optimistic prior, increase in the correlation of states** Holding optimistic prior beliefs constant, an increase in the correlation of states leads to a lower frequency of withdrawals (36\% for low correlation vs 25.83\% for high correlation when \( \alpha = 1/3 \); 29.17\% for low correlation vs 20.42\% for high correlation when \( \alpha = 3/4 \); both significant to the 1\% level). This result corresponds to a departure from the theoretical predictions for these parameters (see table 8 for equilibrium predictions). However, this could be due to the lack of variation in the equilibrium predictions for the treatments with an optimistic prior.\(^{14}\) However, this departure can have an intuitive interpretation based on the idea that an increase in the correlation of states puts a higher weight on the optimistic prior related to the states in Country 1, which would imply a higher probability of the state being high, and thus increase the probability of having a high payoff when rolling over.\(^{15}\)

**Optimistic prior, increase in the precision of the signal about behavior in Country 1** When agents hold an optimistic prior, an increase in the precision of \( y \) leads to a lower frequency of withdrawals (36\% for low precision vs 29.17\% for high precision, when \( s = 1/3 \); 25.83\% for low precision vs 20.42\% for high precision when \( s = 3/4 \); both significant to the 5\% level). These results do not correspond to the predictions of the theory for the discrete model. However, these results can be reconciled with the findings corresponding to the social learning bias, in particular, with the specific way in which agents overreact to the information about the behavior of agents in Country 1. Looking at table 13 we observe, for a given \( s \), a decrease in the percentage of instances in which subjects choose to withdraw after observing signals of agents in Country 1 withdrawing, as the precision of this signal increases from \( \alpha = 1/3 \) to \( \alpha = 3/4 \). In other words, subjects seem to make the mistake related to contagious panics more when \( \alpha = 1/3 \) than when \( \alpha = 3/4 \). These percentages are

\(^{14}\)The main reason for the lack of variation in the theoretical predictions for the discrete model is due to the parameters chosen in the experiment, in particular to the large difference between the payments associated to the two possible actions. Although it would have been desirable to run the experiments with parameters that would exhibit more variability in equilibrium predictions across treatments, given the discrete nature of the model, the parsimonious conditions to ensure a unique equilibrium in global games are lost when moving from continuous to discrete probability distributions. For this reason, the set of parameter combinations for which a unique equilibrium existed for all the different treatments was very restricted, which meant a reduced variation in equilibrium strategies across treatments.

\(^{15}\)Note that, even if the setups are different, the direction of this departure is in line with the qualitative predictions of the model with a continuum of agents.
statistically different to the 1% level of significance when $s = 1/3$ for both cases, i.e. when they observe at least 1 agent withdraw and when they observe exactly 2 agents withdraw in Country 1, and to the 5% level of significance when $s = 3/4$ and they observe a signal that indicates that exactly 2 agents withdraw. Such a reduction in the number of instances in which subjects follow observed withdrawals might explain the overall lower frequency of withdrawals when the precision of the signal about the behavior of agents in Country 1 increases. This, however, goes against the intuition that agents would follow the actions of others when the precision of the information pertaining those actions is higher, not lower.

**Pessimistic prior, increase in the correlation of states** When agents hold a pessimistic prior and $y$ is uninformative ($\alpha = 1/3$), an increase in the correlation of states leads to a higher frequency of withdrawals (33.18% for low correlation vs 42.50% for high correlation, significant to the 1% level). This result is aligned with the predictions for the discrete model.

However, if $y$ is informative ($\alpha = 3/4$), then an increase in the correlation of states has no significant effect on the frequency of withdrawals, which is not aligned with the theory that prescribes a higher frequency of withdrawals when $s = 3/4$ than when $s = 1/3$. This departure from the theory can be explained by looking in table 13 at the treatment characterized by a pessimistic prior and $s = \alpha = 3/4$. As established above, in this case we see a positive effect of contagion, since subjects choose to roll over after observing agents in Country 1 rolling over, even if the theoretical equilibrium action is to withdraw. A direct consequence of this behavior is a lower frequency of withdrawals, which explains this comparative statics result.

**Pessimistic prior, increase in the precision of the signal about behavior in Country 1** Holding the pessimistic prior constant, if the states are uncorrelated ($s = 1/3$), an increase in the precision of $y$ leads to an increase in the frequency of withdrawals (33.18% for low precision vs 38.40% for high precision, significant to the 5% level), which is not aligned with the theoretical predictions. Since the states are uncorrelated, the signal about the behavior of agents in Country 1, $y$, is completely uninformative and should not be taken into consideration for actions. However, as we established when discussing hypothesis 1, the social learning bias leads subjects to overreact to this signal, even in the cases where it is uninformative. Looking at specifications 1 and 3 in table 11 above, we can see not only that this bias is present in both cases, but that the effect of this signal almost doubles in magnitude when $\alpha = 3/4$ than when $\alpha = 1/3$. As interpreted above, when studying the results from table 11, this could be explained by the fact that when $\alpha = 3/4$ the signal about the behavior of agents in Country 1 is giving accurate information about the true behavior of agents, which is a salient feature, but subjects might not realize that this information is irrelevant because they fail to incorporate the fact that $s = 1/3$.

When the states are correlated ($s = 3/4$), on the contrary, an increase in the precision of $y$ does not have a significant effect on the frequency of withdrawals. This result does not go in line with the predictions of the theory for the discrete model, which predicts that the frequency of withdrawals should be higher when the precision of $y$ increases. This departure is analogous to the case stated above with a pessimistic prior and $s = \alpha = 3/4$. Just as
in that case, the reason why we do not observe a higher frequency of withdrawals when \( s = \alpha = 3/4 \) is because this case corresponds to the treatment where we observe evidence for positive contagion, i.e. when subjects roll over in cases where the theoretical equilibrium strategy prescribes withdrawals.

### 5.2.3 Additional results: 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 12 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 beneficial in terms of payoffs 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 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 8. Recall that the predictions for Country 2 in table 8 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 9), we 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 8 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 16 in the appendix contains these empirical equilibrium strategies for each treatment. Based on this empirical equilibrium benchmark, the second type of subjects in the sample corresponds to those who take into account the informative signals and disregard the uninformative ones, and play the game according to this empirical equilibrium. The third type of subjects in the sample are those who take into account the correct information but do not choose actions according to neither of these two types of equilibria. The fourth type of subject takes into consideration uninformative signals or fails to take into account informative ones (i.e. they exhibit one of the information biases studied in hypothesis 1) and thus does not behave in accordance to any equilibrium.\(^{16}\) Finally, subjects in the fifth type

\(^{16}\)Note that when subjects do not choose the correct information set (i.e. when they exhibit one of the
are subjects that behave randomly, i.e. they do not seem to follow a clear pattern in their behavior. 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. Those subjects that exhibit more than 3 deviations are classified as subjects who make random choices.

Table 14 presents, for each treatment, the frequency distributions of these types of subjects and the mean realized payoff of the subjects corresponding to 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, i.e. if playing equilibrium is a better response to the observed distribution of types than any of the other observed strategies.\footnote{This is the type of comparison made for all treatments, except for the ones corresponding to the last two columns of table 14 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 14 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 13 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 14, there is a lot of heterogeneity in individual strategies within each treatment (see El-Gamal and Grether, 1995, for a discussion about the observed heterogeneity of behavioral strategies across subjects and the difficulties to find one unifying theory to explain behavior). We can see from table 14 that there are 4 treatments where the subjects that use the theoretical equilibrium strategy exhibit significantly higher payoffs than those who do not. These treatments correspond to the cases where the prior is optimistic and states are correlated ($s = 3/4$), for both informative and uninformative signals about the behavior in Country 1, and for the cases where the prior is pessimistic, states are correlated ($s = 3/4$) and the signal about behavior in Country 1 is uninformative ($\alpha = 1/3$), or when the prior is pessimistic, states are uncorrelated ($s = 1/3$) and the signal about behavior in Country 1 is informative ($\alpha = 3/4$). Notice that in these four 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 where the highest realized payoffs correspond to the subjects who behave according to equilibrium, 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, i.e. the environment 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.
<table>
<thead>
<tr>
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<th>Pessimistic prior</th>
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<tr>
<td></td>
<td>( s = 1/3 )</td>
<td>( s = 3/4 )</td>
<td>( s = 1/3 )</td>
<td>( s = 3/4 )</td>
</tr>
<tr>
<td>( \alpha = 1/3 )</td>
<td>15%</td>
<td>16.67%</td>
<td>16.67%</td>
<td>25%</td>
</tr>
<tr>
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<td>16.67%</td>
<td>15.1</td>
<td>15.1</td>
</tr>
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<td>Equilibrium</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mean payoff</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Correct info, non-eq</td>
<td>65%</td>
<td>54.16%</td>
<td>54.16%</td>
<td>33.33%</td>
</tr>
<tr>
<td>Mean payoff</td>
<td>8.83</td>
<td>12.17***</td>
<td>11.32</td>
<td>13.57*</td>
</tr>
<tr>
<td>Incorrect info</td>
<td>20%</td>
<td>25%</td>
<td>16.67%</td>
<td>37.5%</td>
</tr>
<tr>
<td>Mean payoff</td>
<td>9.95</td>
<td>12.5***</td>
<td>11.95</td>
<td>13**</td>
</tr>
<tr>
<td>Random</td>
<td>-</td>
<td>4.17%</td>
<td>12.5%</td>
<td>4.17%</td>
</tr>
<tr>
<td>Mean payoff</td>
<td>-</td>
<td>12.6*</td>
<td>7.2***</td>
<td>8.4***</td>
</tr>
</tbody>
</table>

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

Table 14: Individual strategies, by 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 ($s \in \{3/4, 1\}$) and the signal about behavior in Country 1 is informative ($\alpha \in \{3/4, 1\}$). Likewise, we observe a small fraction of subjects who act according to the empirical equilibrium strategy (5% for the case where $s = \alpha = 3/4$ and 12.5% for the case where $s = \alpha = 1$). 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 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 14 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, it seems that the cost is similar when subjects exhibit a bias in information gathering, in particular by paying attention to the uninformative signal about the behavior of agents in Country 1, to the cost, in terms of payoffs, 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 policy implications, this result hints 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.

6 Relation to the literature

The results of this paper are related to different topics in the literature. In particular, we can relate this work to 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. I will first discuss theoretical papers on financial contagion and then introduce the experimental work on this topic. Then, I will focus on social learning experiments to relate the findings of this study to existing results. Finally, I will comment on theoretical and experimental studies on global games.

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. Different authors focus on very specific channels, such as the type of portfolio diversification that leads to contagion in financial markets, or the type of external characteristics among countries that make investors fear a crisis in one market after observing a crisis in a similar market. In the presence of such a plethora of channels, in this paper we have focused on two main classes of channels that encompass the specific channels studied in the literature. In a similar spirit, 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), who focus on the role of cross-market portfolio rebalancing as a source of contagion. In their paper countries share risk factors, which can be as strong as common macroeconomic factors, or as weak as a risk factor with a third country. 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) also present a model of financial contagion through global portfolio diversification but they focus on the social learning channel by modeling contagion as a result of herding behavior. In their model agents have the possibility to pay a cost to remove the uncertainty about the asset’s return, however, it is shown that due to short-selling constraints, the globalization of financial markets weakens the incentives to do so, 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 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 to acknowledge 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. 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, coming through fundamental links. They find that as the asymmetries of information are reduced, the transmission of shocks increase. In contrast to this result, the experimental analysis of the present study does not find a higher incidence of contagion when information becomes more precise. However, as we observe 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). 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.

The two papers above find evidence of fundamental and social learning based contagion, respectively. In particular, 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 levels of liquidity of both banks are identical, or where they are independent. In both papers, subjects only observe the actions of agents in the first bank before making a decision, i.e. 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, i.e. the strength of the social learning channel is not varied in the treatments. 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.

19 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.
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 11 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 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 his or 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) analyze the way in which subjects choose to learn about the state in a social learning context by asking them to choose if they want to observe a private signal about the state, or a public signal about the actions of their predecessors. Subjects are given training in the environment and full feedback in an attempt to minimize mistakes. Duffy et al. (2013) find support for rationality, i.e. they find no particular bias towards private or social learning information, and herd behavior is observed mostly when subjects choose social learning signals, which is an expected result. This is an interesting contrast to the result presented in section 5 about the systematic bias related to social learning that leads agents to respond to this signal, even in the treatments where it is completely uninformative. In those treatments, however, the fact that subjects take this uninformative signal into account for their actions raises the question about the reasons why they do so. Either subjects fail to realize that this 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 hints at the 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, as was first pointed out in the introduction, 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). Manz (2010) and Oh (2013) model contagion between firms, but while Manz (2010) focuses on the revelation of information about a common fundamental factor as the source of contagion, Oh (2013) models how a fundamental link based on common creditors leads to contagion through the inference made by creditors about each other’s types. Ahnert and Bertsch (2013), on the other hand, study a “wake-up” call theory of contagion, where agents in the second market have the possibility to buy a signal about the outcome in the first market. They show that, in equilibrium, when agents buy this signal contagion is more likely to occur, even if the two markets are not correlated.

Finally, the present paper is related to experiments on global games. However, to the author’s knowledge, there are no other papers that study experimentally global games in the context of financial contagion. 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, or 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 (i.e.
threshold strategies), but finds a non-trivial relationship between the specific level of the threshold and the amount of uncertainty in the environment.

7 Conclusions

This paper presented a global games model of financial contagion and the results from an experiment designed to understand the effects of fundamental links and social learning as mechanisms for the transmission of crises between two economies.

While the theory provides very clear predictions about when each of these channels should influence contagion, the experimental results showed some interesting departures from these predictions that are based on two systematic biases in information processing related to each of these channels. The first bias corresponds to a base rate neglect bias, by which subjects underweight the information contained in the prior distribution in treatments where this information should be considered. This bias suggests that the fundamental channel has a smaller impact on decisions than what the theory would predict. The second bias is related to the social learning channel of contagion and is characterized by an overreaction to the signal about the behavior of agents in a foreign country, even in the cases where this signal is uninformative, either because it is not correlated with the true behavior of agents, or because the fundamentals in both countries are not correlated, in which case this signal carries no informative value to agents in the second country.

These biases also explain the observed departures from the comparative statics predicted by the theory and illustrate some behavioral features of decision making that are relevant in this context. In particular, the social learning bias seems to indicate that when information about the behavior of others is available to subjects they find it hard to ignore it, even in cases where such signals carry no relevant information for them. In most cases, subjects take into account this irrelevant information when it implies that agents in the first country have withdrawn their funds, i.e. panics become contagious. As a consequence, agents in the second country react by following this action and withdrawing their funds as well, even if equilibrium would suggest otherwise. However, under specific conditions we see favorable outcomes of this overreaction. In these cases agents in the second country observe actions from agents in the first country that show confidence in their fundamentals, and thus follow these positive actions, even in cases where the theory would prescribe withdrawals, i.e. confidence in fundamentals becomes contagious. This type of positive contagion gives rise to a welfare improvement with respect to the equilibrium actions.

The analysis presented in this paper indicates that one can construct theoretical environments in which contagion should or should not occur, based on two main classes of channels studied in the literature. However, it is of primary importance to understand the way in which agents actually process the information that characterizes these environments. In many cases, the type of information processing might not conform to the rational or Bayesian paradigm of the models and these departures have important consequences in terms of the type of decisions made by subjects and thus on the realized outcomes in the economy and on welfare.
References


8 Appendix

The appendix is composed of three main sections. The first section corresponds to results about the model with a continuum of agents presented in section 2 of the paper. I first present some comparative statics that are not included in the body of the paper because they are not directly related to the fundamental or the social learning channels of contagion. However, they are comparative statics that are normally performed in this type of model. After presenting these additional comparative statics, I present the proofs of the remarks about the comparative statics related to the channels of contagion presented in section 2. The second section of the appendix relates to the discrete model used in the experiment, in particular, it contains the information updating process for the discrete probability distributions and it derives the equilibrium predictions for the different treatments in the experiment. Finally, the third section of the appendix contains some additional tables related to the experimental analysis that are referred to in section 5.

8.1 Model with a continuum of agents

8.1.1 Comparative statics

This section presents a series of remarks about comparative statics that do not affect directly the strength of the two channels of contagion. These comparative statics correspond to the effect that the precision of private signals, $\tau_n$, has on the probability of default in Country $n = 1, 2$, the effect that the mean and the variance of the prior about the state in Country 1, $\mu_1$ and $\tau_1$, respectively, have on the probability of default in Country 1, and the effect that the payoff of early withdrawals, $\lambda_n$, has on the probability of default in Country $n = 1, 2$.

For $n = 1, 2$, the following hold:

**Remark A 1.**  
If the probability of default in Country $n$ is low and agents have an optimistic prior about the state of the economy, then more precise private information, $\tau_n$, will lead to a higher threshold $x_n^*$ (i.e. to a higher incidence of withdrawal) and to an increase in the probability of default in Country $n$.

2. If the probability of default in Country $n$ is high and agents have a pessimistic prior about the state of the economy, then more precise private information, $\tau_n$, will lead to a lower threshold $x_n^*$ (i.e. to a lower probability of withdrawal) and to a decrease in the probability of default in Country $n$. 


Proof. I first analyze the results for Country 1. Notice that

\[
\frac{dx_1^*}{d\tau_1} = -\frac{\tau_{\theta_1}}{\tau_1} + \frac{\tau_{\theta_2}}{\tau_1} \mu_\theta + \frac{\Phi^{-1}(1-\lambda_1)(\tau_{\theta_1} + \frac{1}{2}\tau_1)}{\tau_1 \sqrt{\tau_{\theta_1} + \tau_1}} \]

So when \( \theta_1^* < \mu_\theta + \frac{\Phi^{-1}(1-\lambda_1)(\tau_{\theta_1} + \frac{1}{2}\tau_1)}{\tau_{\theta_1} \sqrt{\tau_{\theta_1} + \tau_1}} \) i.e. when default is not very likely to occur and agents have an optimistic prior about the state of the economy, then a higher precision of the private signal will lead to a higher threshold \( x_1^* \), and thus to a higher incidence of withdrawal. On the other hand, when \( \theta_1^* > \mu_\theta + \frac{\Phi^{-1}(1-\lambda_1)(\tau_{\theta_1} + \frac{1}{2}\tau_1)}{\tau_{\theta_1} \sqrt{\tau_{\theta_1} + \tau_1}} \), i.e. when default is likely to occur and agents have a pessimistic prior about the state of the economy, then a higher precision of the private signal will lead to a lower threshold \( x_1^* \), which effectively means a lower probability of withdrawal.

The effects of an increased precision of the private signal on the probability of default, \( \theta_1^* \) are consistent with the previous result, since

\[
\frac{d\theta_1^*}{d\tau_1} = \phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta_1^* - \mu_\theta - \Phi^{-1}(1-\lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \times
\left[ -\frac{1}{2} \frac{\tau_{\theta_1}}{(\tau_1)^{3/2}} \left( \theta_1^* - \mu_\theta - \Phi^{-1}(1-\lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) - \frac{1}{2} \Phi^{-1}(1-\lambda_1) \frac{1}{\sqrt{\tau_1} \sqrt{\tau_{\theta_1} + \tau_1}} + \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \frac{d\theta_1^*}{d\tau_1} \right]
= \frac{1}{2} \left[ \phi \left( \frac{\tau_{\theta_1}}{(\tau_1)^{3/2}} \left( \theta_1^* - \mu_\theta - \Phi^{-1}(1-\lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \left[ \frac{\tau_{\theta_1}}{(\tau_1)^{3/2}} \left( \theta_1^* - \mu_\theta - \Phi^{-1}(1-\lambda_1) \frac{\tau_{\theta_1}}{\sqrt{\tau_{\theta_1} + \tau_1}} \right) \right] \right]
- \phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta_1^* - \mu_\theta - \Phi^{-1}(1-\lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \frac{d\theta_1^*}{d\tau_1}
\]

To determine whether \( \frac{d\theta_1^*}{d\tau_1} \) is positive or negative, we need to sign the term

\[
\left[ \frac{\tau_{\theta_1}}{(\tau_1)^{3/2}} \left( \theta_1^* - \mu_\theta - \Phi^{-1}(1-\lambda_1) \frac{\tau_{\theta_1}}{\sqrt{\tau_{\theta_1} + \tau_1}} \right) \right]
\]

If \( \theta_1^* < \mu_\theta + \Phi^{-1}(1-\lambda_1) \frac{\tau_{\theta_1}}{\sqrt{\tau_{\theta_1} + \tau_1}} \), then \( \frac{d\theta_1^*}{d\tau_1} > 0 \), i.e. if agents have an optimistic prior about the state of the economy and \( \theta_1^* \) is low enough, i.e. default is not very likely to occur, then more precise private information will increase \( \theta_1^* \), which increases the probability of default.

Alternatively, if \( \theta_1^* > \mu_\theta + \Phi^{-1}(1-\lambda_1) \frac{\tau_{\theta_1}}{\sqrt{\tau_{\theta_1} + \tau_1}} \), then \( \frac{d\theta_1^*}{d\tau_1} < 0 \), so that if agents have a pessimistic prior and \( \theta_1^* \) is high enough (i.e. default is very likely to occur), then more precise information will decrease \( \theta_1^* \), thus decreasing the probability of a default. This means that when agents are pessimistic, having a more precise signal will lead them to put more weight on it, thus decreasing the probability of a default.
I perform the same analysis for Country 2. From equations 16 and 8 we can write \( x_2^* \) as

\[
x_2^* = \frac{(\hat{\eta} + \tau_2)}{\tau_2} \theta_2^* - \frac{\hat{\eta}}{\tau_2} \theta_1 - \frac{\Phi^{-1}(1 - \lambda_2)}{\tau_2} \sqrt{\hat{\eta} + \tau_2}
\]

where \( \hat{\eta} = (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}) \). Therefore,

\[
\frac{dx_2^*}{d\tau_2} = \frac{\tau_2 - \hat{\eta} - \tau_2 \theta_2^* + \frac{\hat{\eta}}{\tau_2} \theta_1}{\frac{1}{2} \tau_2 (\frac{\hat{\eta} + \tau_2}{\hat{\eta}})^{-1/2} - \sqrt{\frac{\hat{\eta} + \tau_2}{\hat{\eta}}}} - \frac{\Phi^{-1}(1 - \lambda_2)}{\tau_2} \frac{1}{\tau_2} \sqrt{\hat{\eta} + \tau_2}
\]

\[
= -\frac{\hat{\eta}}{\tau_2} \theta_2^* + \frac{\hat{\eta}}{\tau_2} \theta_1 + \frac{\Phi^{-1}(1 - \lambda_2) \left(\frac{1}{2} \tau_2 + \hat{\eta}\right)}{\tau_2 \sqrt{\hat{\eta} + \tau_2}}
\]

So when \( \theta_2^* < \hat{\theta}_1 + \frac{\Phi^{-1}(1 - \lambda_2)}{\hat{\eta} \sqrt{\hat{\eta} + \tau_2}} \) i.e. when default is not very likely to occur and agents are ex-ante optimistic about the state of the economy, then a higher precision of the private signal will lead to a higher threshold \( x_1^* \), and thus to a higher incidence of withdrawal. On the other hand, when \( \theta_2^* > \hat{\theta}_1 + \frac{\Phi^{-1}(1 - \lambda_2)}{\hat{\eta} \sqrt{\hat{\eta} + \tau_2}} \), i.e. when default is likely to occur and agents are ex-ante pessimistic about the state of the economy, then a higher precision of the private signal will lead to a lower threshold \( x_2^* \), which effectively means a lower probability of withdrawal.

Similarly, the effect on the probability of default in Country 2 given an increase in the precision of private signals \( \tau_2 \) is the following:

\[
\frac{d\theta_2^*}{d\tau_2} = \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1}(1 - \lambda_2) \right) \right) \times
\]

\[
\left[ -\frac{1}{2} \frac{\hat{\eta}}{\sqrt{\tau_2}} (\theta_2^* - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1}(1 - \lambda_2)) + \frac{\hat{\eta}}{\sqrt{\tau_2}} \frac{d\theta_2^*}{d\tau_2} - \frac{1}{2} \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \frac{\hat{\eta} + \tau_2}{\hat{\eta}} \right)^{-1/2} \right]
\]

\[
= \frac{1}{2} \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1}(1 - \lambda_2) \right) \right) \times
\]

\[
1 - \frac{\hat{\eta}}{\sqrt{\tau_2}} \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1}(1 - \lambda_2) \right) \right)
\]

where \( \hat{\eta} = (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}) \).
To determine whether $\frac{\partial \theta_1}{\partial \tau_1}$ is positive or negative, we need to sign the term

$$
\left[ \frac{\hat{\eta}}{\tau_2^{3/2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{\hat{\eta}}{\hat{\eta}\sqrt{\hat{\eta} + \tau_2}} \Phi^{-1}(1 - \lambda_2) \right) \right]
$$

If $\theta_2^* < \hat{\theta}_1 + \frac{\hat{\eta}}{\hat{\eta}\sqrt{\hat{\eta} + \tau_2}} \Phi^{-1}(1 - \lambda_2)$, then $\frac{\partial \theta_1}{\partial \tau_1} > 0$, i.e. if default is not likely to occur (i.e. $\theta_2^*$ is low enough) and agents’ public signals make them are optimistic about the state of the economy, then more precise private information will increase $\theta_1^*$, which increases the probability of default.

Alternatively, if $\theta_2^* > \hat{\theta}_1 + \frac{\hat{\eta}}{\hat{\eta}\sqrt{\hat{\eta} + \tau_2}} \Phi^{-1}(1 - \lambda_2)$, then $\frac{\partial \theta_1}{\partial \tau_1} < 0$, so that if default is very likely to occur (i.e. $\theta_2^*$ is high enough) and agents are pessimistic (low $\hat{\theta}_1$), then more precise information will lead agents to assign a higher weight on their private information, thus giving a lower weight on their initial pessimistic beliefs about the state, which decreases the probability of a default by decreasing $\theta_1^*$. The intuition for this result is the following. Creditors use both private and public information to assess whether they should withdraw their funds or roll over their loans. In order to roll over their loans, they need to make sure that fundamentals are in a good state and that other agents will not withdraw their funds. Thus, in intermediate states, a creditor wants to coordinate her action with the others to either roll over their debt and avoid a default, or to withdraw her funds early and provoke the country to default. Private signals have a direct incentive on the coordination effect, so the higher the precision of the private signal, $\tau_n$, the more likely it is for creditors to coordinate because their information sets will be more aligned. In addition, a higher precision of the private signal increases the weight that creditors assign to it, thus decreasing the weight given to public information. Therefore, when creditors have an optimistic prior about the state of the economy and believe that default is not very likely to occur, creditors refrain from withdrawing their funds because they know that the probability of default is small. However, an increase in the precision of their private signal will lead them to put less weight on their prior belief that the state is good, thus increasing the individual probability of withdrawal (by increasing their threshold $x_n^*$), which also increases the probability of default with respect to the case of a lower precision of private signals. This means that when agents have an optimistic prior, a higher precision of private information might lead them to withdraw their funds more often with respect to what they would have done if they had just followed their initial optimistic beliefs. A similar logic applies to the case where agents have a pessimistic prior about the state of the economy and believe that the probability of a default is high. These results are consistent with those presented by Metz (2002) in a similar setup.

**Remark A 2** In Country 1, the public signal $\mu_\theta$ decreases the probability of a default.
Proof.

$$\frac{d\theta^{*}_1}{d\mu_\theta} = \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \Phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta^{*}_1 - \mu_\theta + \Phi^{-1} \left( \lambda_1 \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \right) \left[ \frac{d\theta^{*}_1}{d\mu_\theta} - 1 \right]$$

$$\frac{d\theta^{*}_1}{d\mu_\theta} = -\frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \Phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta^{*}_1 - \mu_\theta + \Phi^{-1} \left( \lambda_1 \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \right) < 0$$

The higher the mean of the prior $\mu_\theta$ (or the public signal), the more optimistic creditors are about the state of the economy. A higher $\mu_\theta$ decreases $\theta^{*}_1$, which implies that the range of values of $\theta_1$ for which the country stays solvent increases (i.e. default occurs for $\theta < \theta^{*}_1$, so if $\theta^{*}_1$ decreases, then default is less likely to occur).

Remark A 3 1. If the probability of default in Country 1 is low and agents have an optimistic prior about the state of the economy, then a higher transparency of public information, $\tau_{\theta_1}$, will further decrease the probability of default in Country 1.

2. If the probability of default in Country 1 is high and agents have a pessimistic prior about the state of the economy, then a higher transparency of public information, $\tau_{\theta_1}$, will further increase the probability of default in Country 1.

Proof.

$$\frac{d\theta^{*}_1}{d\tau_{\theta_1}} = \Phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta^{*}_1 - \mu_\theta - \Phi^{-1} \left( 1 - \lambda_1 \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \right) \times$$

$$\left[ \frac{1}{\sqrt{\tau_1}} \left( \theta^{*}_1 - \mu_\theta - \Phi^{-1} \left( 1 - \lambda_1 \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \right]$$

$$= \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \Phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta^{*}_1 - \mu_\theta - \Phi^{-1} \left( 1 - \lambda_1 \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \right) \times$$

$$1 - \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \Phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta^{*}_1 - \mu_\theta - \Phi^{-1} \left( 1 - \lambda_1 \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \right)$$

In order to determine how the probability of default is affected by changes in the precision of the public signal, we need to determine the sign of $\left( \theta^{*}_1 - \mu_\theta - \frac{1}{2} \Phi^{-1} \left( 1 - \lambda_1 \frac{1}{\sqrt{\tau_{\theta_1} + \tau_1}} \right) \right)$. In particular, if $\theta^{*}_1 < \mu_\theta + \frac{1}{2} \Phi^{-1} \left( 1 - \lambda_1 \frac{1}{\sqrt{\tau_{\theta_1} + \tau_1}} \right)$, then $\frac{d\theta^{*}_1}{d\tau_{\theta_1}} < 0$, which implies that when agents have an optimistic prior and the probability of default is small, then a higher transparency of the public signal will reinforce these optimistic beliefs and lead to an even lower probability of default. On the other hand, if $\theta^{*}_1 > \mu_\theta + \frac{1}{2} \Phi^{-1} \left( 1 - \lambda_1 \frac{1}{\sqrt{\tau_{\theta_1} + \tau_1}} \right)$, then creditors are ex-ante pessimistic about the state of the economy and believe that the probability of
default is large, so a higher precision of the public signal will exacerbate this pessimism and lead to an even higher probability of default.

The intuition behind this result is analogous to the one above for the case on an increase in the precision of private signals. If agents have an optimistic prior and the probability of default is small, then an increase in the precision of the public signal will further decrease the probability of default. In contrast to the private signal, the public signal only contains information about the fundamental and is included in every agent’s information set. Thus, when the precision of the public signal increases, agents will assign a higher weight to the public signal, which would reinforce their initial optimistic beliefs, thus making them less likely to withdraw their funds, which would in turn reduce the likelihood of a default. On the other hand, if creditors have a pessimistic prior and the probability of default is high, a higher precision of the public signal will exacerbate this pessimism and lead agents to give a higher weight to it, thus increasing the incidence of withdrawals and the probability of a default, since agents believe that the state is probably not good and that the proportion of withdrawals required to default is small. This result is consistent with Morris and Shin (2002) and Metz (2002), who highlight that more transparency of public information does not necessarily lead to higher welfare since in some cases it might increase the probability of a default. ■

**Remark A 4** The probability of a default in Country \( n = 1, 2 \) increases with an increase in \( \lambda_n \).

**Proof.** Notice that

\[
\frac{d\theta^*_1}{d\lambda_1} = \phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta^*_1 - \mu_\theta - \Phi^{-1} (1 - \lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \left[ -\frac{\tau_{\theta_1} + \tau_1}{\tau_1} \frac{d\Phi^{-1} (1 - \lambda_1)}{d\lambda_1} + \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \frac{d\theta^*_1}{d\lambda_1} \right]
\]

\[
= -\phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta^*_1 - \mu_\theta - \Phi^{-1} (1 - \lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) \frac{\tau_{\theta_1} + \tau_1}{\tau_1} \frac{d\Phi^{-1} (1 - \lambda_1)}{d\lambda_1}
\]

Since \( \frac{d\Phi^{-1} (1 - \lambda_1)}{d\lambda_1} < 0 \) and \( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \phi \left( \frac{\tau_{\theta_1}}{\sqrt{\tau_1}} \left( \theta^*_1 - \mu_\theta + \Phi^{-1} (\lambda_1) \frac{\sqrt{\tau_{\theta_1} + \tau_1}}{\tau_{\theta_1}} \right) \right) < 1 \), by the uniqueness
condition. Likewise, for Country 2

$$
\frac{d\theta^*_2}{d\lambda_2} = \left[1 - \phi \left(\frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}}{\sqrt{\tau_2}} \left(\theta_2^* - \tilde{\theta}_1 - \frac{\sqrt{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}} - \tau_{\theta_2}^{-1}}{\sqrt{\tau_2}} \Phi^{-1}(1 - \lambda_2)\right)\right)\right]
$$

Since $\frac{d\Phi^{-1}(1-\lambda_2)}{d\lambda_2} < 0$ and $\frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}}{\sqrt{\tau_2}} \phi(\cdot) < 1$, by the uniqueness condition. This means that, in each individual country, as the payoff from early withdrawal increases, the incentives to withdraw funds, and thus provoke a default, increase. ■

8.1.2 Comparative statics about the channels of contagion: proofs

The following lemma will be useful to prove some comparative statics results about the channels of contagion.

**Lemma A 1.** 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 transparency of public information, measured by the precision of the composed public signal $\widehat{\eta}$, will further decrease the probability of default in Country 2.

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 transparency of public information, measured by the precision of the composed public signal $\widehat{\eta}$, will further increase the probability of default in Country 2.

**Proof.** Recall from section 2 that all public information held by agents in Country 2 can be summarized by

$$
\theta_2|y \sim N\left(\frac{\tau_{\theta_1} \mu_{\theta} + \widehat{\eta} \widehat{y}}{\tau_{\theta_1} + \eta}, \tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}\right)
$$

where $\widehat{y} = x_1^* - \tau_1^{-1/2} y$ and $\widehat{\eta} = \tau_1 \eta$. For simplicity, let $\widehat{\eta} = (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1}$ be the precision of the composed public information held by agents in Country 2. What we are interested in is the effect of some of the components of the term $\widehat{\eta}$ on the probability of default in Country 2, in particular I will focus on the effect of the correlation between fundamentals in countries 1 and 2, measured by the precision of $\theta_2$, $\tau_{\theta_2}$, and on the effect of the precision of the public signal about the proportion of agents that withdraw their funds.
in Country 1 ($\eta$). In order to study those effects we first explore the effect that $\hat{\eta}$ has on the probability of default in Country 2.

\[
\frac{d\theta^*_2}{d\hat{\eta}} = \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1} (1 - \lambda_2) \right) \right) \times \\
\left[ \frac{1}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1} (1 - \lambda_2) \right) \right] \\
- \Phi^{-1} (1 - \lambda_2) \left( \frac{1}{\hat{\eta}} \left( \frac{1}{\sqrt{\tau_2}} \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \right)^{1/2} - \sqrt{\hat{\eta} + \tau_2} \right) + \frac{\hat{\eta}}{\sqrt{\tau_2}} \frac{d\theta^*_2}{d\hat{\eta}} \\
= \frac{1}{1 - \frac{\hat{\eta}}{\sqrt{\tau_2}} \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1} (1 - \lambda_2) \right) \right)} \times \\
\left[ \frac{1}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1} (1 - \lambda_2) \right) \right] \\
- \Phi^{-1} (1 - \lambda_2) \left( \frac{1}{\hat{\eta}} \left( \frac{1}{\sqrt{\tau_2}} \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \right)^{1/2} - \sqrt{\hat{\eta} + \tau_2} \right) + \frac{\hat{\eta}}{\sqrt{\tau_2}} \frac{d\theta^*_2}{d\hat{\eta}} \\n
\text{In order to determine how the probability of default in Country 2 is affected by changes in the precision of the aggregate public signal, we need to determine the sign of the term} \\
\left( \theta^*_2 - \hat{\theta}_1 - \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}} \right). \\
\text{If} \theta^*_2 < \hat{\theta}_1 + \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}}, \text{then} \frac{d\theta^*_2}{d\hat{\eta}} < 0, \text{which implies that when agents have an optimistic prior about the state of the economy in Country 2 and the probability of default is low, then an increase in the precision of the public signal will further decrease the probability of default since agents set a higher weight on the public information, which makes them feel even more optimistic about the economy, and thus less likely to withdraw their funds, thus reducing the likelihood of a default.}

\text{On the other hand, if} \theta^*_2 > \hat{\theta}_1 + \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}}, \text{then creditors believe that the probability of default is high and have a pessimistic prior about the state of the economy, so a higher precision of the public signal will lead to an even higher probability of default in Country 2. An increase in the precision of the public information will exacerbate this pessimism and lead agents to put more weight on the public signal, which would eventually lead to an even higher probability of default in Country 2. Just as in the case of Country 1, more precise public information does not necessarily lead to a lower probability of default.}

\textbf{Remark 1} 

1. \textit{If the probability of default in Country 2 is low and agents are ex-ante optimistic about the state of the economy, then a higher correlation between Country 1 and Country 2 (i.e. a higher precision $\tau_{\theta_2}$) will further decrease the probability of default in Country 2.}

2. \textit{If the probability of default in Country 2 is high and agents are ex-ante pessimistic about the state of the economy, then a higher correlation between Country 1 and Country 2 (i.e. a higher precision $\tau_{\theta_2}$) will increase the probability of default in Country 2.}

Remark 1
Proof. From lemma A1 we know that

\[
\frac{d\theta^*_2}{d\hat{\eta}} = \frac{\phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \sqrt{\frac{\hat{\eta} + \tau_2}{\hat{\eta}}} \Phi^{-1} (1 - \lambda_2) \right) \right)}{1 - \frac{\hat{\eta}}{\sqrt{\tau_2}} \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \sqrt{\frac{\hat{\eta} + \tau_2}{\hat{\eta}}} \Phi^{-1} (1 - \lambda_2) \right) \right)} \left[ \frac{1}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}} \right) \right] \]

And notice that

\[
\frac{d\hat{\eta}}{d\tau_{\theta_2}} = (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tau_{1\eta})^{-1})^{-2} \tau_{\theta_2}^{-2} > 0
\]

Where \(\hat{\eta} = (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tau_{1\eta})^{-1})^{-1}\) is the precision of the composed public signal held by agents in Country 2. We now simply apply the chain rule to find that

\[
\frac{d\theta^*_2}{d\tau_{\theta_2}} = \frac{d\theta^*_2}{d\hat{\eta}} \cdot \frac{d\hat{\eta}}{d\tau_{\theta_2}} = \frac{\phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \sqrt{\frac{\hat{\eta} + \tau_2}{\hat{\eta}}} \Phi^{-1} (1 - \lambda_2) \right) \right)}{1 - \frac{\hat{\eta}}{\sqrt{\tau_2}} \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \sqrt{\frac{\hat{\eta} + \tau_2}{\hat{\eta}}} \Phi^{-1} (1 - \lambda_2) \right) \right)} \left[ \frac{1}{\sqrt{\tau_2}} \left( \theta^*_2 - \hat{\theta}_1 - \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}} \right) \right] \times (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tau_{1\eta})^{-1})^{-2} \tau_{\theta_2}^{-2}
\]

The sign of \(\frac{d\theta^*_2}{d\tau_{\theta_2}}\) depends on the sign of the term \(\left( \theta^*_2 - \hat{\theta}_1 - \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}} \right)\). In particular, if \(\theta^*_2 < \hat{\theta}_1 + \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}}\), then \(\frac{d\theta^*_2}{d\tau_{\theta_2}} < 0\), i.e. if the probability of default is low and agents have an optimistic prior about fundamentals, then a higher correlation between countries 1 and 2 will further decrease the probability of default. On the other hand, if \(\theta^*_2 > \hat{\theta}_1 + \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}}\), then creditors believe that the probability of default is high and are ex-ante pessimistic about the state of the economy. A similar logic applies as in the previous case, so a higher correlation between the two countries will exacerbate this pessimism by leading agents to give a higher weight to the aggregate public signal, thus increasing the incidence of withdrawals and the probability of a default, since agents know that the state is probably not good and that the proportion of withdrawals required to default is small. ■

Remark 2 A higher signal about the proportion of agents that withdraw their funds in Country 1, \(y\), increases the probability of default in Country 2.

Proof. To prove this result I first analyze the effect that an increase in the posterior mean \(\hat{\theta}_1\) has on the probability of default in Country 2 and then we apply the chain rule to isolate the effect of the signal about the proportion of agents that withdraw their funds in Country
1, \( y \).

\[
\frac{d\theta^*_2}{d\theta_1} = \phi \left( \frac{(\tau^{-1}_\theta + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1}}{\sqrt{\tau}} \left( \theta^*_2 - \hat{\theta}_1 - \frac{\sqrt{(\tau\theta_2^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}}{(\tau\theta_2^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1}} \Phi^{-1} \left( 1 - \lambda_2 \right) \right) \right) \times \\
\left[ \frac{(\tau\theta_2^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1}}{\sqrt{\tau}} \right]^{-1} \frac{d\theta^*_1}{d\theta_1} - \frac{(\tau\theta_2^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1}}{\sqrt{\tau}} \left( \theta^*_2 - \hat{\theta}_1 - \frac{\sqrt{(\tau\theta_2^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1} + \tau_2}}{(\tau\theta_2^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1})^{-1}} \Phi^{-1} \left( 1 - \lambda_2 \right) \right) \\
< 0
\]

Therefore, a higher expected or posterior mean will lead to a lower probability of default, i.e. the higher the posterior mean \( \theta_1 \), the more optimistic creditors are about the state of the economy in Country 2. To analyze the effect on \( \theta^*_2 \) of the signal about the proportion of agents that withdraw their funds in Country 1, notice that

\[
\hat{\theta}_1 = \frac{\tau_{\theta_1} \mu_\theta + \hat{\eta} y}{\tau_{\theta_1} + \hat{\eta}} = \frac{\tau_{\theta_1} \mu_\theta + \tau_1 \eta \left( x_1^* - \tau_1^{-1/2} y \right)}{\tau_{\theta_1} + \tau_1 \eta}
\]

So that

\[
\frac{d\hat{\theta}_1}{dy} = \frac{-\eta \tau_1^{-1/2}}{\tau_{\theta_1} + \tau_1 \eta} < 0
\]

By the chain rule, we can establish that

\[
\frac{d\theta^*_2}{dy} = \frac{d\theta^*_2}{d\theta_1} \cdot \frac{d\theta_1}{dy} > 0
\]

**Effect of an increase in \( \eta \) on the probability of default in Country 2.** A change in \( \eta \) affects both the posterior mean, \( \hat{\theta}_1 \), and the precision of the composed public signal through \( \hat{\eta} = (\tau\theta_2^{-1} + (\tau_{\theta_1} + \tau_1 \eta)^{-1})^{-1} \). This leads to a “coordination” effect which makes agents put more weight on the posterior mean and to an “information effect” which changes the level of this mean. I derive some expressions to investigate the overall effect, however, it is not possible to fully characterize it analytically.

Recall that \( \hat{\theta}_1 = \frac{\tau\theta_1 \mu_{\theta} + \tau_1 \eta \hat{y}}{\tau\theta_1 + \tau_1 \eta} \) and \( \hat{\eta} = (\tau\theta_2^{-1} + (\tau_{\theta_1} + \tau_1 \eta)^{-1})^{-1} \).

We first look at the effect that the precision of the public signal, \( \hat{\eta} \), has on the probability
of default in Country 2 (coordination effect, without decomposing it):

\[
\frac{d\theta_2^*}{d\hat{\eta}} = \frac{\phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \sqrt{\hat{\eta} + \tau_2} \Phi^{-1} (1 - \lambda_2) \right) \right)}{1 - \frac{\hat{\eta}}{\sqrt{\tau_2}} \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \sqrt{\hat{\eta} + \tau_2} \Phi^{-1} (1 - \lambda_2) \right) \right)} \begin{cases} 
> 0 & \text{if } \theta_2^* > \hat{\theta}_1 + \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}} \\
< 0 & \text{if } \theta_2^* < \hat{\theta}_1 + \frac{1}{2} \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\hat{\eta} + \tau_2}} 
\end{cases}
\]

Notice that the precision of the public signal \( \hat{\eta} \) is increasing in \( \eta \):

\[
\frac{d\hat{\eta}}{d\eta} = (\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \tau_1 \eta)^{-1})^{-2} (\tau_{\theta_1} + \tau_1 \eta)^{-2} \tau_1 \\
> 0
\]

Now we look at the effect of the posterior mean \( \hat{\theta}_1 \) on the probability of default in Country 2 (information effect, without decomposing it):

\[
\frac{d\theta_2^*}{d\hat{\theta}_1} = \frac{-\left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}}{\sqrt{\tau_2}} \right)^{-1} \phi \left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}}{\sqrt{\tau_2}} \right) \left( \theta_2^* - \hat{\theta}_1 - \sqrt{\left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}}{\sqrt{\tau_2}} \right)^{-1} + \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\tau_2}} (1 - \lambda_2) \right) \right)}{1 - \left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}}{\sqrt{\tau_2}} \right)^{-1} \phi \left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}}{\sqrt{\tau_2}} \right) \left( \theta_2^* - \hat{\theta}_1 - \sqrt{\left( \frac{\tau_{\theta_2}^{-1} + (\tau_{\theta_1} + \hat{\eta})^{-1}}{\sqrt{\tau_2}} \right)^{-1} + \frac{\Phi^{-1}(1-\lambda_2)}{\sqrt{\tau_2}} (1 - \lambda_2) \right) \right)}
\]

< 0

which is unambiguously negative. Now we look at how \( \eta \) affects the posterior mean of the distribution about \( \theta_2 \):

\[
\frac{d\hat{\theta}_1}{d\eta} = \frac{\tau_1 \hat{y} (\tau_{\theta_1} + \tau_1 \eta) - \tau_1 (\tau_{\theta_1} \mu_\theta + \tau_1 \hat{\eta})}{(\tau_{\theta_1} + \tau_1 \eta)^2} \\
\frac{d\hat{\theta}_1}{d\eta} = \frac{\tau_1 \tau_{\theta_1} (\hat{y} - \mu_\theta)}{(\tau_{\theta_1} + \tau_1 \eta)^2} \begin{cases} 
> 0 & \text{if } x_1^* > \mu_\theta + \tau_1^{-1/2} y \\
< 0 & \text{if } x_1^* < \mu_\theta + \tau_1^{-1/2} y 
\end{cases}
\]

(26)

Since \( \hat{y} = x_1^* - \tau_1^{-1/2} y \). The effect of the precision of the signal about the proportion of withdrawing agents in Country 1 on the posterior mean \( \hat{\theta}_1 \) depends on the relative magnitudes of the equilibrium threshold used by creditors in Country 1, the prior beliefs of agents in Country 1 (measured by the mean of the prior \( \mu_\theta \)), and the signal about the proportion of agents that withdraw their funds in Country 1, \( y \). We take one step back and analyze the effect of the mean of the prior \( \mu_\theta \) on the optimal threshold for agents in Country 1, \( x_1^* \). Recall
that \( x_1^* = \frac{\tau_1}{\tau_1 + \tau_{\theta_1}} \theta_1^* - \frac{\Phi^{-1}(1-\lambda_1)(\tau_\theta_1 + \tau_\tau)}{\tau_1 \sqrt{\tau_\theta_1 + \tau_\tau}} - \frac{\tau_\theta_1}{\tau_1} \mu_\theta. \)

\[
\frac{dx_1^*}{d\mu_\theta} = \frac{(\tau_\theta_1 + \tau_1)}{\tau_1} \frac{d\theta_1^*}{d\mu_\theta} - \frac{\tau_\theta_1}{\tau_1} 
= -\frac{(\tau_\theta_1 + \tau_1)}{\tau_1} \frac{\tau_\theta_1}{\sqrt{\tau_\theta_1}} \phi \left( \frac{\tau_\theta_1}{\sqrt{\tau_\theta_1}} \left( \theta_1^* - \mu_\theta + \Phi^{-1}(\lambda_1) \frac{\sqrt{\tau_\theta_1 + \tau_\tau}}{\tau_\theta_1} \right) \right) - \frac{\tau_\theta_1}{\tau_1} < 0
\]

So an increase in the mean of the prior \( \mu_\theta \) decreases thresholds. On the other hand, when creditors in Country 1 set a low threshold they withdraw their funds for a smaller range of signals, which leads creditors in Country 2 to observe signals about a lower proportion of agents that withdraw their funds in Country 1, \( y \). This implies that a high \( \mu_\theta \) is associated with a low \( x_1^* \), which leads to a low \( y \), and a low \( \mu_\theta \) is associated with a high \( x_1^* \), which leads to a high \( y \). However, notice that \( y \) enters condition 26 multiplied by the standard deviation of private signals in Country 1, \( \tau_{\theta_1} \), which we assume to be low enough (high \( \tau_1 \)) for the uniqueness condition.

Now we characterize the effect of a change in the precision of the public signal about the proportion of agents that withdraw in Country 1 on the probability of default in Country 2.

\[
\frac{d\theta_2^*}{d\eta} = \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1}(1-\lambda_2) \right) \right) \times 
\frac{1}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1}(1-\lambda_2) \right) \cdot \frac{d\hat{\eta}}{d\eta} + 
\frac{d\theta_2^*}{d\eta} \left( \frac{1}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1}(1-\lambda_2) \right) \right) 
\]

\[
= \frac{\tau_1}{\sqrt{\tau_2}} \phi \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{\sqrt{\hat{\eta} + \tau_2}}{\hat{\eta}} \Phi^{-1}(1-\lambda_2) \right) \left( \frac{\hat{\eta}}{\tau_{\theta_1}} (\tau_{\theta_2} + \tau_1 \eta)^{-2} \right) - \frac{\tau_{\theta_1} (\tau_{\theta_1} - \hat{\theta}_2)}{(\tau_{\theta_1} + \tau_1 \eta)^2} \right) 
\]

Proof. The sign of this derivative will depend on the sign of the term

\[
\left[ \frac{1}{\sqrt{\tau_2}} \left( \theta_2^* - \hat{\theta}_1 - \frac{1}{2} \left( \frac{\hat{\eta}}{\sqrt{\tau_2}} \right)^{-1/2} \Phi^{-1}(1-\lambda_2) \right) \left( \frac{\hat{\eta}}{2} \left( \tau_{\theta_1} + \tau_1 \eta \right)^{-2} \right) - \frac{\hat{\eta} \tau_{\theta_1} \left( \hat{\eta} - \mu_\theta \right)}{(\tau_{\theta_1} + \tau_1 \eta)^2} \right]
\]

which illustrates the two effects that we have described, i.e. the coordination effect through the first term and the information effect through the term through the second term. As is clear from the expression above, it is not possible to sign this term for all parameter values, which is why in the body of the paper I present results based on numerical simulations. ■
8.2 Discrete model

This section contains the information updating process in Country 1 and Country 2 in the discrete model and the equilibrium for the parameters used in the different treatments of the experiment.

8.2.1 Country 1

Recall that Pr (L1) = p, Pr (M1) = q, Pr (H1) = 1 − p − q, and private signals follow the conditional distribution:

<table>
<thead>
<tr>
<th></th>
<th>L1</th>
<th>M1</th>
<th>H1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pr (l1</td>
<td>·)</td>
<td>r</td>
<td>(1−r)</td>
</tr>
<tr>
<td>Pr (m1</td>
<td>·)</td>
<td>(1−r)</td>
<td>r</td>
</tr>
<tr>
<td>Pr (h1</td>
<td>·)</td>
<td>(1−r)</td>
<td>(1−r)</td>
</tr>
</tbody>
</table>

Posterior beliefs take the following form:
If \( x_i^1 \in \{l_1, m_1, h_1\} \) is observed:

\[
\Pr \left( \theta_1 | x_i^1 \right) = \frac{\Pr \left( x_i^1 | \theta_1 \right) \Pr \left( \theta_1 \right)}{\Pr \left( x_i^1 \right)}
\]

we find the equilibrium action, for each possible realization of the private signal. We do this for the two parametrizations used in the experiment.

When agents have a pessimistic prior \((p = 0.65, q = 0.175)\), agents will find it optimal to withdraw \( (a_i^1 = 0) \) when they observe signal \( l_1 \) and they will roll over \( (a_i^1 = 1) \) when observing signals \( \{m_1, h_1\} \). Denote \( \sigma_j \left( a_i^1 = 1 \right) \) the probability that player \( j \neq i \) chooses action \( a_i^j = 1 \). This is clearly a conditional probability that takes an interesting form, but for simplicity we will show that, regardless of its functional form and value, agents will have a dominant strategy. Notice that for these parameters:

If \( x_i^1 = l_1 \), player \( i \) will withdraw since

\[
X \left[ \Pr \left( M_1 | l_1 \right) \sigma_j \left( a_i^j = 1 \right) + \Pr \left( H_1 | l_1 \right) \right] < \lambda_i
\]

\[
20 \left[ 0.076 \sigma_j \left( a_i^j = 1 \right) + 0.076 \right] < 4
\]

for all \( \sigma_j \left( a_i^j = 1 \right) \in [0, 1] \).

If \( x_i^1 = h_1 \), player \( i \) will roll over since

\[
X \left[ \Pr \left( M_1 | h_1 \right) \sigma_j \left( a_i^j = 1 \right) + \Pr \left( H_1 | h_1 \right) \right] > \lambda_i
\]

\[
20 \left[ 0.389 \sigma_j \left( a_i^j = 1 \right) + 0.389 \right] > 4
\]

for all \( \sigma_j \left( a_i^j = 1 \right) \in [0, 1] \).

Given this information (i.e. it is dominant to withdraw when \( x_i^1 = l_1 \) and it is dominant to roll over when \( x_i^1 = h_1 \)), when \( x_i^1 = m_1 \) agents will roll over since:

\[
\frac{\Pr \left( x_i^1 | \theta_1 \right) \Pr \left( \theta_1 \right)}{\Pr \left( x_i^1 \right)} > \frac{1}{20}
\]
\[
X \left[ \Pr (H_1|m_1) + \Pr (x^i_1 = h_1|M_1) \Pr (M_1|x^i_1 = m_1) \\
+ \Pr (x^i_1 = m_1|M_1) \Pr (M_1|x^i_1 = m_1) \sigma_j^{x^i_1=m_1} (a^i_1 = 1) \right]
> \frac{\lambda_1}{20} \left[ 0.207 + 0.233\sigma_j^{x^i_1=m_1} (a^i_1 = 1) \right] > 4
\]

for all \( \sigma_j^{x^i_1=m_1} (a^i_1 = 1) \in [0, 1] \).

We now do the same exercise for the second parametrization in Country 1 when agents have an optimistic prior, i.e. \( p = 0.175, q = 0.175 \). In this case agents will always find it optimal to roll over, for all private signals \( x^i_1 \in \{ l_1, m_1, h_1 \} \).

If \( x^i_1 = l_1 \), player \( i \) will roll over since
\[
X \left[ \Pr (M_1|l_1) \sigma_j (a^i_1 = 1) + \Pr (H_1|l_1) \right]
> \frac{\lambda_1}{20} [0.149 \sigma_j (a^i_1 = 1) + 0.553] > 4
\]

for all \( \sigma_j (a^i_1 = 1) \in [0, 1] \).

If \( x^i_1 = m_1 \), player \( i \) will roll over since
\[
X \left[ \Pr (M_1|m_1) \sigma_j (a^i_1 = 1) + \Pr (H_1|m_1) \right]
> \frac{\lambda_1}{20} [0.106 \sigma_j (a^i_1 = 1) + 0.788] > 4
\]

for all \( \sigma_j (a^i_1 = 1) \in [0, 1] \).

Finally, if \( x^i_1 = h_1 \), player \( i \) will roll over since
\[
X \left[ \Pr (M_1|h_1) \sigma_j (a^i_1 = 1) + \Pr (H_1|h_1) \right]
> \frac{\lambda_1}{20} [0.106 \sigma_j (a^i_1 = 1) + 0.788] > 4
\]

for all \( \sigma_j (a^i_1 = 1) \in [0, 1] \).

### 8.2.2 Country 2

Recall that in Country 2 the conditional distributions for the state, private signals, and the signal about the behavior of agents in Country 1, \( y \), take the following form:

| \( \Pr (L_2|\cdot) \) | \( L_1 \) | \( M_1 \) | \( H_1 \) |
|-----------------|--------|--------|--------|
| \( \Pr (M_2|\cdot) \) | \( \frac{1-s}{2} \) | \( \frac{1-s}{2} \) | \( \frac{1-s}{2} \) |
| \( \Pr (H_2|\cdot) \) | \( \frac{1-s}{2} \) | \( \frac{1-s}{2} \) | \( s \) |

| \( \Pr (y = 0|\theta_1, \cdot) \) | \( w = 0 \) | \( w = 1 \) | \( w = 2 \) |
|-----------------|--------|--------|--------|
| \( \alpha \) | \( \frac{(1-\alpha)}{2} \) | \( \frac{(1-\alpha)}{2} \) | \( \frac{(1-\alpha)}{2} \) |
| \( \Pr (y = 1|\theta_1, \cdot) \) | \( \frac{(1-\alpha)}{2} \) | \( \alpha \) | \( \frac{(1-\alpha)}{2} \) |
| \( \Pr (y = 2|\theta_1, \cdot) \) | \( \frac{(1-\alpha)}{2} \) | \( \frac{(1-\alpha)}{2} \) | \( \alpha \) |
After observing signal $y$ agents in Country 2 update their beliefs about the state in Country 1 in the following way. If they observe $y \in \{0, 1, 1\}$:

$$
\Pr(\theta_1|y) = \frac{\Pr(y|\theta_1) \Pr(\theta_1)}{\Pr(y)}
$$

Where

$$
\Pr(y = 0|\theta_1) = \alpha \Pr(w = 0|\theta_1) + \frac{(1-\alpha)}{2} \Pr(w = 1|\theta_1) + \frac{(1-\alpha)}{2} \Pr(w = 2|\theta_1)
$$

$$
\Pr(y = 1|\theta_1) = \frac{(1-\alpha)}{2} \Pr(w = 0|\theta_1) + \alpha \Pr(w = 1|\theta_1) + \frac{(1-\alpha)}{2} \Pr(w = 2|\theta_1)
$$

$$
\Pr(y = 2|\theta_1) = \frac{(1-\alpha)}{2} \Pr(w = 0|\theta_1) + \frac{(1-\alpha)}{2} \Pr(w = 1|\theta_1) + \alpha \Pr(w = 2|\theta_1)
$$

and

$$
\Pr(w = 0|\theta_1) = (1 - \Pr(a_i = 0|\theta_1))^2
$$

$$
\Pr(w = 1|\theta_1) = \Pr(a_i = 0|\theta_1) (1 - \Pr(a_i = 0|\theta_1))
$$

$$
\Pr(w = 2|\theta_1) = \Pr(a_i = 0|\theta_1)^2
$$

and recall that $a_i = 0$ corresponds to the action where agent $i$ decides to withdraw.

To define $\Pr(w|\theta_1)$ it is necessary to understand how agents in Country 1 behave in equilibrium for each set of priors (optimistic and pessimistic). The following table contains the individual probability of withdrawing, given each possible state in Country 1:

<table>
<thead>
<tr>
<th></th>
<th>Pessimistic $(p = 0.65, q = 0.175)$</th>
<th>Optimistic $(p = 0.175, q = 0.65)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Pr(a_i = 0</td>
<td>L_1)$</td>
<td>$\Pr(l_1</td>
</tr>
<tr>
<td>$\Pr(a_i = 0</td>
<td>M_1)$</td>
<td>$\Pr(l_1</td>
</tr>
<tr>
<td>$\Pr(a_i = 0</td>
<td>H_1)$</td>
<td>$\Pr(l_1</td>
</tr>
<tr>
<td>$\Pr(w = 0</td>
<td>L_1)$</td>
<td>$(1-r)^2$</td>
</tr>
<tr>
<td>$\Pr(w = 0</td>
<td>M_1)$</td>
<td>$(1+r)^2$</td>
</tr>
<tr>
<td>$\Pr(w = 0</td>
<td>H_1)$</td>
<td>$(1+r)^2$</td>
</tr>
<tr>
<td>$\Pr(w = 1</td>
<td>L_1)$</td>
<td>$r (1 - r)$</td>
</tr>
<tr>
<td>$\Pr(w = 1</td>
<td>M_1)$</td>
<td>$\frac{1-r^2}{4}$</td>
</tr>
<tr>
<td>$\Pr(w = 1</td>
<td>H_1)$</td>
<td>$\frac{1-r^2}{4}$</td>
</tr>
<tr>
<td>$\Pr(w = 2</td>
<td>L_1)$</td>
<td>$r^2$</td>
</tr>
<tr>
<td>$\Pr(w = 2</td>
<td>M_1)$</td>
<td>$\frac{(1-r)^2}{4}$</td>
</tr>
<tr>
<td>$\Pr(w = 2</td>
<td>H_1)$</td>
<td>$\frac{(1-r)^2}{4}$</td>
</tr>
</tbody>
</table>

Agents in Country 2 care about the state in Country 2, which is correlated with the state in Country 1 by the parameter $s$.

Updating the prior beliefs about the state in Country 2 (getting the posterior or updated probability distribution of $\theta_2$ given $y$), we define:
\[
\Pr(\theta_2|y) = \Pr(\theta_2|L_1)\Pr(L_1|y) + \Pr(\theta_2|M_1)\Pr(M_1|y) + \Pr(\theta_2|H_1)\Pr(H_1|y)
\]

It is now time to introduce the private signals for agents in Country 2 into consideration to get an expression about the posterior beliefs about \( \theta_2 \) once all signals have been observed. Recall that private signals in Country 2 have the same structure as private signals in Country 1. First, we get the conditional probabilities of \( x_2^i \), given \( y \) and \( \theta_2 \).

\[
\Pr(x_2^i|\theta_2, y) = \Pr(x_2^i|\theta_2)\Pr(\theta_2|y)
\]

Given all these information, we do Bayesian updating about the realization of states in Country 2.

\[
\Pr(\theta_2|x_2^i, y) = \frac{\Pr(x_2^i|\theta_2, y)\Pr(\theta_2|y)}{\Pr(x_2^i|y)}
\]

**Equilibrium** For each treatments related to Country 2 there will be monotonicity in actions, but the specific ordering (combinations of \( x_2^i \) and \( y \)) will depend on parameters. In particular, whenever \( \alpha = 1/3 \) or \( s = 1/3 \), the ordering should follow only monotonicity with respect to private signals, regardless of signal \( y \).

**Treatments: Optimistic prior** \( \{ p = 0.175, q = 0.175, r = 0.6 \} \)

For all the treatments where we induce an optimistic prior \( (p = 0.175, q = 0.175) \), agents will always find it optimal to roll over, for all signals

\[
(x_2^i, y) \in \{ (l_2, 2), (l_2, 1), (l_2, 0), (m_2, 2), (m_2, 1), (m_2, 0), (h_2, 2), (h_2, 1), (h_2, 0) \}
\]

It is not surprising to see that the expected value of rolling over for a given private signal \( x_2^i \in \{ l_2, m_2, h_2 \} \) does not vary with the observed signals \( y \in \{ 0, 1, 2 \} \), since agents in Country 2 know that agents in Country 1 will always roll over in equilibrium when the prior is optimistic.

**Treatments: Pessimistic prior** \( \{ p = 0.65, q = 0.175, r = 0.6 \} \)

For the case where agents have a pessimistic prior, agents in Country 1 withdraw their funds when observing a private signal \( x_2^i = l_1 \), and roll over when \( x_2^i \in \{ m_1, h_1 \} \).

In terms of equilibrium strategies, in the treatments where the states of Countries 1 and 2 are uncorrelated \( (s = 1/3, \text{treatments C2 (6) and C2 (8)}) \) the equilibrium strategy is to

\[
\Pr(\theta_2|y) = \frac{\Pr(x_2^i|\theta_2, y)\Pr(\theta_2|y)}{\Pr(x_2^i|y)}
\]

---

20When \( \alpha = 1/3 \), even if the states are highly correlated, the information observed about the number of agents that withdraw in Country 1 is meaningless to subjects in Country 2 because getting a signal \( y \in \{ 0, 1, 2 \} \) means that there could have been 0, 1, or 2 withdrawals with equal probability. If \( s = 1/3 \), even if the signal about the number of withdrawing agents is very precise, subjects should not pay attention to it because, even if they could infer with high accuracy the realized state \( \theta_1 \), the state in Country 2 would be \( \theta_2 \in \{ L_2, M_2, H_2 \} \) with equal probability, regardless of the realization of the state in Country 1.

21For treatment 5, where signal \( y \) is perfectly precise (\( \alpha = 1 \)), notice that in equilibrium agents should never observe even one agents rolling over \( y \in \{ 1, 2 \} \), since in equilibrium agents in Country 1 always rollover. In the expression for \( E(a_0^2 = 1|x_2^i, y \in \{ 1, 2 \}) \) we assume that when agents in Country 2 observe out of equilibrium actions they just disregard that information and base their beliefs only on their private signal and the prior.
always roll over, which is due to the fact that the pessimistic prior in Country 1 does not carry over to Country 2. In treatment C2 (7), where the states are highly correlated \((s = 3/4)\) but the signal about behavior in Country 1 is uninformative \((\alpha = 1/3)\), agents should only take into consideration their private signal, so in equilibrium they should withdraw when \(x_2^i = l_2\), and roll over when \(x_2^i \not\in \{m_2, h_2\}\). In treatment C2 (9), where the states are highly correlated \((s = 3/4)\) and the signal about behavior of agents in Country 1 is precise \((\alpha = 3/4)\), the equilibrium actions depend on the realization of both private signals and the signal about behavior in Country 1. In particular, in equilibrium agents in Country 2 roll over whenever they observe a signal about 0 people withdrawing in Country 1 \((y = 0)\), or when they observe 1 person withdrawing and their private signal is high \((x_2^i = h_2 \text{ and } y = 1)\). For all the other cases, in equilibrium they should withdraw. Finally, it is intuitive to expect that for treatment C2(10), where \(\theta_1\) and \(\theta_2\) are perfectly correlated and the signal \(y\) is perfectly precise \((s = 1, \alpha = 1)\), in equilibrium agents in Country 2 will disregard their private signals and base their actions solely on the signal \(y\). In particular, agents will withdraw if \(y \in \{1, 2\}\) and roll over when \(y = 0\).

### 8.3 Experimental results: additional tables

<table>
<thead>
<tr>
<th></th>
<th>(s = 1/3)</th>
<th>(s = 3/4)</th>
<th>(s = 1/3)</th>
<th>(s = 3/4)</th>
<th>(s = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x_2^i)</td>
<td>3.641***</td>
<td>3.957***</td>
<td>3.987***</td>
<td>3.249***</td>
<td>2.302***</td>
</tr>
<tr>
<td>(y_{roll})</td>
<td>0.63**</td>
<td>0.681***</td>
<td>1.25***</td>
<td>1.874***</td>
<td>1.048***</td>
</tr>
<tr>
<td>(d_{prior} \times x_i)</td>
<td>-0.025</td>
<td>-0.922</td>
<td>-0.155</td>
<td>(-0.024)**</td>
<td>-2.953***</td>
</tr>
<tr>
<td>(d_{prior} \times y_{roll})</td>
<td>0.598*</td>
<td>0.055</td>
<td>0.418</td>
<td>(-0.263)**</td>
<td>1.08***</td>
</tr>
<tr>
<td>risk aversion</td>
<td>0.196</td>
<td>-0.829***</td>
<td>-0.036</td>
<td>-0.878***</td>
<td>0.031</td>
</tr>
<tr>
<td>(C)</td>
<td>-2.426***</td>
<td>-2.261***</td>
<td>-3.355***</td>
<td>1.579</td>
<td>-1.524</td>
</tr>
</tbody>
</table>

Clustered (by subject) standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 15: Logit estimates of information taken into account for individual actions, by treatment
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Induced prior</th>
<th>Correlation of states (s)</th>
<th>Precision of y (alpha)</th>
<th>Equilibrium actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2: 1</td>
<td>Optimistic</td>
<td>Uninformative (1/3)</td>
<td>Uninformative (1/3)</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>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>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>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 5</td>
<td>Optimistic</td>
<td>Perfect (1)</td>
<td>Perfect (1)</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>Roll over for x=m and x=h</td>
</tr>
<tr>
<td>C2: 7</td>
<td>Pessimistic</td>
<td>High (3/4)</td>
<td>Uninformative (1/3)</td>
<td>Roll over for all signals</td>
</tr>
<tr>
<td>C2: 8</td>
<td>Pessimistic</td>
<td>Uninformative (1/3)</td>
<td>High (3/4)</td>
<td>Roll over for x=h, y=0 &amp; x=m</td>
</tr>
<tr>
<td>C2: 9</td>
<td>Pessimistic</td>
<td>High (3/4)</td>
<td>High (3/4)</td>
<td>Roll over for y=0 &amp; x=m, y=0 &amp; x=h</td>
</tr>
<tr>
<td>C2: 10</td>
<td>Pessimistic</td>
<td>Perfect (1)</td>
<td>Perfect (1)</td>
<td>Roll over for all signals</td>
</tr>
</tbody>
</table>

Table 16: "Empirical" equilibrium predictions for Country 2, given observed behavior in Country 1