Contributions to Economic Analysis & Policy

Volume 1, *Issue* 1 2002 *Article* 6

Credits, Crises, and Capital Controls: A Microeconomic Analysis

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Contributions to Economic Analysis & Policy is one of *The B.E. Journals in Economic Analysis & Policy*, produced by The Berkeley Electronic Press (bepress). http://www.bepress.com/bejeap

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Abstract

We analyze the behavior of foreign banks who sequentially provide credit to finance projects in an emerging market. The foreign banks are exposed to both project−risks and the macro−economic risk of a currency crisis, and there are no bailout guarantees. Nevertheless, we show that it is often the case that banks provide too much credit too easily and that this behavior may precipitate the onset of a currency crisis. We demonstrate how the imposition of capital controls in the form of taxes and subsidies on foreign investment may improve the situation. Whereas most of the literature on currency crises focuses its analysis on debtor countries and thus on the borrowers' side, our paper illustrates that the lenders' side also deserves attention.

1. Introduction

In recent years several countries around the world have gone through a type of international economic crisis that is often referred to as a "currency crisis": the "Tequila crisis" in 1994-5, the "Asian crisis" in 1997, the "Russian crisis" in 1998, and the Latin American crisis in 1999.[1] Just recently, Turkey has come dangerously close to the brink and Argentina has become the most recent victim. Despite their ominous names, such international economic crises do not seem to be particularly rare or unique events. In fact, Lindgren *et al.* (1996, p. 20), for example, count as many as eighty to a hundred financial crises over the past quarter century.[2] These so-called currency crises typically involve the following three essential "ingredients": a debtor country, foreign creditors, and credits that are denominated in some international currency, such as US dollars.[3] While it is doubtless the case that it is the interaction among these three factors that precipitates international currency crises, in this paper we confine our analysis to the issue of the behavior of foreign creditors.

Specifically, we consider the behavior of foreign banks that invest in an emerging market,[4] and we focus our attention on the logical implications of three interrelated stylized facts. First, there is the phenomenon of herding, by which we refer to a situation where foreign banks flock to a few global "hot spots," such as emerging markets in Southeast Asia.[5] Second, when a currency crisis occurs, no creditor enjoys priority in access to the country's international reserves. Finally, third, due to the presence of fixed costs, and perhaps for other reasons too, the competition among the foreign banks is imperfect. Consequently, there are (excess) expected profits to be made and thus there is "competition for clients" among the foreign banks.[6]

We consider a model where foreign banks finance local long-term projects by short-term credits that are denominated in foreign currency. The foreign banks face two kinds of risk: the "macro-economic" risk of a currency crisis, and "project-risk" or the prospect of project failure. We assume that the foreign banks move sequentially, obtain a private signal about the project-risk associated with the projects they consider financing, and observe the actions

[1] Often, the sharp fall in the value of the local currency is the *consequence* rather than the *cause* of the crisis, although in itself, the decline in the value of the local currency may contribute, sometimes dramatically, to further deterioration.

[2] This number includes domestic financial crises.

[3] In theory, a currency crisis can occur without foreign creditors, similarly to Krugman (1979). A country that refrains from foreign credits may use its foreign exchange reserves to finance a trade deficit, and when these reserves fall below a critical level domestic agents may trigger a crisis. However, if no foreign creditors are involved, the country can prevent an attack on its currency by restricting access to its foreign exchange market. Thus, at least for the case of emerging markets, which we consider in this paper, foreign creditors are an essential ingredient of a currency crisis.

[4] Bank lending has significantly contributed to the extraordinarily rapid growth and volatility of short-term international capital movements in the 1990s. Moreover, as Eichengreen and Mody (2000, p. 6) point out, "international bank lending is particularly important for private-sector borrowers".

[5] For example, Eichengreen and Mody (2000, p. 12) report that out of 5115 LIBOR-based loans 3373 were to East Asia.

[6] Hughes and Mester (1998) provide evidence that banks of all sizes exhibit significant economies of scale. Such evidence implies that there cannot be perfect competition in the banking sector.

of all previous foreign banks. We analyze the equilibria of this model and show that they are generally inefficient. In particular, for a wide range of parameter values, foreign banks provide too many credits too easily and thus generate an inefficiently high risk of a currency crisis. For other parameter values, foreign banks inefficiently provide no credits at all. We demonstrate how the imposition of capital controls through taxes and subsidies on short-term foreign credit can improve the situation.

In contrast to other papers on currency crises, we deal with the lenders' side, not the borrowers' side. Neither do we consider the issue of the viability of financial institutions in the debtor country, nor anything else concerning the debtor country's behavior. As regards the lenders, we concentrate on foreign banks' incentives for *providing* credit rather than on their incentives to *withdraw* the credits supplied once a crisis is anticipated. Moreover, we do not assume that foreign banks enjoy bailout guarantees.[7] Finally, whereas most of the literature on currency crises focuses on a variety of weaknesses of the debtor countries, our paper illustrates that the lenders' side merits some attention as well.

The results of our analysis have some implications with respect to the present debate among economists and policy-makers about the costs and benefits of "globalization," at least in as much as globalization is interpreted as implying the relaxation of constraints on short-term capital inflows. We describe a clearly identified set of situations where imposing controls on short-term capital inflows can well prove to be beneficial.[8] In addition, we sketch a role for the IMF and the World Bank as coordinators of consortia of private banks.

The analysis proceeds as follows. In the next section, we present the theoretical model. In Section 3 we examine equilibrium behavior, and in Section 4 we study its efficiency properties. In Section 5 we show that an informed reliance on taxes and subsidies can at least secure an appropriately defined second-best outcome and may even achieve efficiency. We offer some conclusions in Section 6. All proofs are relegated to Appendix A. Appendix B contains details of the calculations of the numerical examples.

[7] Schneider and Tornell (1999), for example, distinguish between two classes of models in the literature on currency crises. One that assumes the existence of government bailout guarantees and focuses its attention on the implied moral hazard problem for the foreign banks, and the other which involves the existence of "multiple equilibria based on illiquidity." (p. 4). Additional references are provided therein. See also Chang and Velasco (1999), Furman and Stiglitz (1998), Sachs et al. (1996), and Burnside et al. (2001). Diamond and Rajan (2000) present a model where financial institutions that are deliberately fragile in order to solve a commitment problem, melt down in a bank run if an unanticipated shock occurs.

[8] Others have made similar recommendations. Krugman (1999), for example, writes "my own suggestion is that governments actively try to discourage local companies from borrowing in foreign currencies, and also perhaps from relying too much on borrowed funds in general (that is, reduce their "leverage"). The best way to do this is probably by taxing companies that borrow in foreign currency." (p. 165). This position is shared by Stiglitz (1999) who has been widely quoted on the subject in the popular press (see, e.g., Louis Uchitelle's article in *The New York Times*, December 2, 1999). Another proponent of taxing short-term capital inflows to emerging markets is Eichengreen (see, e.g., Eichengreen 1999, pp. 49-51). For a different view and for additional references see Edwards (1999) and Reinhart and Smith (2001).

2. The Model

We consider a hypothetical "emerging market," and a countably infinite number of ex-ante identical foreign banks. Each foreign bank is able to provide at most C standardized short-term credits that are denominated in some "international currency." The exchange rate between the emerging market's local currency and the international currency is assumed to be fixed, provided of course that no currency crisis has occurred. We assume that the emerging market has within it $2C$ "investment opportunities" or projects, each of which requires one standardized credit and yields stochastic returns (predominantly) in local currency.[9,10] For the purpose of our discussion, it does not matter whether the foreign banks provide these projects with direct financing, or whether financing is provided via domestic local banks. We normalize the foreign banks' opportunity costs of capital to zero, so that they will want to finance local projects if and only if they yield a positive expected return.[11] Below, we sometimes refer to the act of providing credit by a bank as investment.

The game proceeds through three stages, the first of which is divided into a large number of short periods denoted by $t \in \{1, 2, ...\}$. In the first stage of the game, the foreign banks move sequentially, inspect projects within the country, and decide about whether or not to provide short-term credit. The credits are short-term in the sense that they are due at the second stage, but the projects can only be completed at the third stage.[12] In the second stage of the game, a currency crisis may occur if the country's foreign reserves drop sufficiently below its obligations denominated in foreign currency.[13] A currency crisis causes

[9] The assumption that the number of investment opportunities is $2C$, and hence the number of credits given is less or equal to $2C$, is a simplified version of the assumption that there is a finite number of investment opportunities in which foreign banks may possibly be interested. We interpret C as "a few," and $2C$ as "many" credits. Extending the model to include the case where the number of investment opportunities is kC for some $k > 2$, is cumbersome and does not generate additional significant insights.

[10] An additional reason for why not more than $2C$ credits may be provided is the presence of negative payoff externalities. As will become clearer below, the provision of credit increases the probability of a currency crisis thereby reducing the expected profit from all provided credits.

[11] Notice that a positive expected return is sufficient for investment but not necessary. We assume however that a bank does not invest if its expected payoff is equal to zero. Our results do not depend on this tie-breaking assumption.

[12] We do not analyze the reason for why banks provide only short-term as opposed to long-term credit. One reason, among others, may be incomplete contracting. For example, foreign banks may not be able to control the riskiness of the project or the effort level of the debtor, but may be able to observe the debtor's choice after a short period. A bank can prevent the debtor from choosing too risky projects or a low level of effort by conditioning the renewal of the short-term credit upon satisfactory performance. Similarly, short-term credits enable a bank to react to additional information about the project's profitability that it may receive at some intermediate stage of the project (Rajan, 1992). Another reason has been recently stressed by Diamond and Rajan (2000), who show that short-term financing by many creditors may serve as a commitment device for domestic banks. Additional explanations can also be given; however, for whatever reason, we note that it is often the case that banks finance long-term projects through short-term credits in practice.

[13] Recent empirical work (see, e.g., Chang and Velasco, 1998; Furman and Stiglitz, 1999; Kaminsky et al. 1998; Rodrik and Velasco, 1999; and Tornell, 1999) presents evidence that supports the hypothesis that a currency crisis is triggered by a country's foreign reserves dropping sufficiently below its foreign currency denominated debt. See Morris and Shin (1998) and Heinemann (2000) for a theoretical model where this can

those projects that are financed by the foreign banks to be terminated at a great loss to the foreign banks. If a currency crisis does not occur, the short-term credits are renewed, and the game proceeds into the third stage. In the third stage, the projects are completed and the foreign banks receive a payment that is positively related to the projects' success.

A state of the world $\omega = (\theta, \lambda) \in \{\theta_1, \theta_2, \theta_3\} \times \{\lambda_L, \lambda_H\} = \Omega$ is thus assumed to consist of a "macro-component" $\theta \in \{\theta_1, \theta_2, \theta_3\}$ and a "project-component" $\lambda \in \{\lambda_L, \lambda_H\}$. A commonly known prior distribution $\Pr(\omega)$ describes the probability of the various states of the world. We assume that θ and λ are independent, that is $\Pr(\omega) = \Pr(\theta)\Pr(\lambda)$ for every $\omega \in \Omega$. The macro-component θ captures the risk of a currency crisis (which may depend on the total number of short-term credits provided by the banks), whereas the project-component λ captures the risk of project failure.

Consider the macro-component θ first. We assume that when $\theta = \theta_1$, a currency crisis occurs if the foreign banks have provided any positive number of credits. When $\theta = \theta_2$, a currency crisis occurs if the foreign banks have provided a total of more than C credits. When $\theta = \theta_3$, a currency crisis never occurs, regardless of the total number of credits provided by the foreign banks. Thus, θ_1 is interpreted as a "bad" event where the provision of even a "few" credits triggers a crisis; θ_2 is interpreted as a "intermediate" event where only the provision of "many" credits triggers a crisis; and θ_3 is interpreted as a "good" event where even if many credits are provided, no crisis occurs.

These assumptions about the relation between a currency crisis, the number of credits provided, and the event θ can be justified as follows. Assume that at the second stage of the game, the ratio of the country's foreign reserves divided by the total amount of short-term claims is given by a random variable $R(\theta, \gamma)$, where γ denotes the total number of short-term credits that international banks have provided by the end of the first stage of the game. Although additional credits may increase foreign reserves ceteris paribus, it is reasonable to assume that the elasticity of foreign reserves with respect to short-term credits is less than 1, i.e., that the ratio $R(\theta, \gamma)$ is decreasing in γ. Since this plausible assumption is all we need for the subsequent analysis, we don't model explicitly how reserves react to outstanding debt. Following the literature mentioned in footnote 13 above, assume that the ratio $R(\theta, \gamma)$ determines whether or not a currency crisis occurs. Specifically, assume that if the ratio $R(\theta, \gamma)$ falls below a certain minimum, then "speculators" launch an attack on the country's local currency that results in a currency crisis. Note that according to this scenario, the currency crisis is triggered by an international wave of speculation and cannot be prevented by the creditor banks. Even if foreign banks were willing to renew their credits, the currency crisis could not be avoided. Consequently, it is optimal for them to take part in a "bank run" on the country's foreign reserves that triggers the crisis once it occurs. Finally, by providing short-term credits that are denominated in international currency, the creditor banks influence the probability that a currency crisis occurs because the higher γ, the lower $R(\theta, \gamma)$. We assume that the ratio $R(\theta, \gamma)$ falls below the critical minimum that triggers a speculative attack whenever either $\theta = \theta_1$ and $\gamma > 0$ or $\theta = \theta_2$ and $\gamma > C$. The relation

be reproduced as the unique equilibrium outcome (cf. also Chan and Chiu, 2002, and the references therein for arguments that bring back multiplicity of equilibrium).

between a currency crisis, the number of credits provided, and the event θ that we assumed in the previous paragraph follows.

The project-component λ is related to the projects' success. We assume that conditional on λ, all projects have the same probability of being successful, and interpret $\lambda = \lambda_L$ as indicative of a low probability of success, and $\lambda = \lambda_H$ as indicative of a high probability of success. The implied correlation among the projects' likelihood of success is motivated by the fact that projects' success is likely to be significantly positively correlated in the type of environments we consider.[14,15] Of course, this does not imply that the realizations ("success" or "failure," respectively) are identical for all projects.

To summarize, we are interested in the three following events: (1) a currency crisis occurs, (2) a currency crisis does not occur, but the projects mostly fail, and (3) a currency crisis does not occur, and the projects mostly succeed.

We assume that before a bank decides whether or not to provide credit, it "inspects" the projects and obtains a private signal about their associated project-risk. The public nature of macro-risks implies that all foreign banks are equally informed about them, and have expectations that are given by the prior distribution. A foreign bank's private signal $s \in \{s_L, s_U, s_H\}$, $s_L < s_U < s_H$, can either be low and indicative of project failure ($s = s_L$), high and indicative of project success ($s = s_H$), or uninformative ($s = s_U$), which is equivalent to getting no signal at all. More specifically, letting $\Pr(s\,|\lambda)$ denote the probability that a foreign bank observes the signal s when the state of the world is λ, we assume that $\Pr(s_L\,|\lambda_L) = \Pr(s_H\,|\lambda_H) > \Pr(s_L\,|\lambda_H) = \Pr(s_H\,|\lambda_L) \geq 0$, and $\Pr(s_U\,|\lambda_L) = \Pr(s_U\,|\lambda_H) \geq 0$. That is, the distribution that relates the private signals to the state of the world is symmetric so that good and bad signals "cancel" each other and are together equivalent to the uninformative signal.

Recall that the first stage of the game is divided into a large number of short periods $t \in \{1, 2, ...\}$. In every such period t, one randomly selected foreign bank (bank t) observes projects within the country, obtains a private signal, denoted s_t, about the projects' chances of success, and decides whether or not to provide credit ("invest"). Conditional on any bank's information, all projects are identical. Furthermore, by assumption, the probability of a currency crisis depends only on whether the bank invests at all (but not on how many credits it provides when it invests). Therefore, each bank will either provide no credits at all or C credits. We denote the actions of the foreign banks by $a \in \{0, 1\}$, where $a = 0$ means that a bank declines to provide any credits, and $a = 1$ means that a bank provides C credits. The action of the bank that moves at time $t \in \{1, 2, ...\}$ is denoted a_t. The bank that moves at time t observes the actions of all the banks that moved before it in periods

[14] Consider for example the case of investments in holiday resort projects in Southeast Asia. The success of such projects is highly correlated because it depends on common geographic and cultural characteristics, as well as on other common variables that determine whether the country where the resorts are located becomes an attractive international tourist destination.

[15] Since the projects' success is correlated, the risk associated with λ may also be interpreted as a "macro" risk. However, whereas a currency crisis is a purely macro-event, the projects' success has a micro dimension, as the previous footnote illustrates. At any rate, the point of the terminology is to help distinguish between these two different types of risks. It is not meant to have any further implications.

$\tau \in \{1, ..., t-1\}$, but not their signals. Thus, the information that is available to bank t consists of its own private signal s_t and the history of actions $h_{t-1} = \{a_1, ..., a_{t-1}\}$. We assume that this process continues as long as the country has not yet received $2C$ credits, and banks are still willing to provide credit if they observe a favorable enough signal. The first stage of the game ends when either of these two requirements stops being satisfied.

Foreign banks' preferences are described as follows: A bank that does not provide any credit enjoys a payoff of zero in every state of the world. The payoff of a foreign bank that has provided C credits depends on the state of the world, and on the total number of credits that have been provided by the end of the first stage of the game, $\gamma \in \{0, C, 2C\}$. Specifically, banks' payoffs are described by the function,

$$\pi(a_t, \gamma, \omega) = \begin{cases} 0 & \text{if } a_t = 0 \\ y & \text{if } a_t = 1 \text{ and a currency crisis occurs} \\ x_L & \text{if } a_t = 1 \text{, a currency crisis does not occur but the projects mostly fail} \\ x_H & \text{if } a_t = 1 \text{, a currency crisis does not occur and the projects mostly succeed} \end{cases}$$

where $y < 0$ and $x_L < 0 < x_H$.[16] We assume that conditional on the state of the world, all the foreign banks that have provided credits receive the same payoff.[17] In case of a currency crisis, the payoff to a foreign bank that has provided credit is negative ($y < 0$). When no currency crisis occurs, a bank's payoff is negative in case the projects mostly fail ($x_L < 0$) and positive in case the projects mostly succeed ($x_H > 0$).

This model gives rise to three different types of externalities. First, there is an *informational externality* that is due to the fact that the banks' actions may reveal their signals, which are valuable because they provide useful information about the true state of the world. Second, there is a *payoff externality* that is caused by the fact that additional credits increase the probability of a currency crisis and therefore reduce the expected payoff of those banks that have already provided credit. Finally, a "business stealing effect" is present too. The fact that the number of credits is limited, together with the fact that each bank that provides credit expects a positive expected payoff, imply that a bank that succeeds in approaching the country early, eliminates the profit opportunities of other banks who were slower to respond.

3. Equilibrium

Denote the set of all possible histories by $\mathcal{H}$. A (pure) strategy for the banks is a function $\sigma : \mathcal{H} \times \{s_L, s_U, s_H\} \rightarrow \{0, 1\}$ that maps the observed history of previous banks' actions and a bank's own private signal into a decision about whether or not to provide C credits. A belief is a function $\beta : \mathcal{H} \times \{s_L, s_U, s_H\} \rightarrow \bigcup_{\tau \geq 1} \Delta(s_L, s_U, s_H)^\tau$, where $\Delta(s_L, s_U, s_H)$ denotes the set of all probability distributions over (s_L, s_U, s_H), that maps the observed history and

[16] Recall that the number of credits that the country has received by the end of the first stage of the game, γ, affects the probability that a currency crisis occurs.

[17] Thus, we assume that when a currency crisis occurs, no bank has priority over another with respect to the country's foreign reserves. In particular, foreign reserves are not provided as collateral.

a bank's own signal at any time t into $t-1$ probability distributions (beliefs) over the signals observed by the $t-1$ banks that moved before it, respectively. With slight abuse of notation, we denote the strategy and belief of the bank that moves at time t by σ_t and β_t, respectively. We focus our attention on pure strategy perfect Bayesian equilibria (PBE) (see, e.g., Osborne and Rubinstein, 1994).

Definition. *A profile of strategies and beliefs* $\{(\sigma_t, \beta_t)\}_{t=1}^{\infty}$ *is a perfect Bayesian equilibrium (PBE) of the game above, if (1) for every* $t \in \{1, 2, ...\}$, *the strategy of the bank that moves at time* t *maximizes its expected payoff given its beliefs about the signals of the previous banks and the other banks' strategies; and (2) whenever possible, beliefs are updated according to Bayes' rule.*

We have the following proposition,

Proposition 1. *(i) A pure strategy PBE exists;*
(ii) in every pure strategy PBE, banks' strategies are non-decreasing in their signals; and,
(iii) the first stage of the game ends in finite time.

Recall that there are two ways in which the first stage of the game may end. Either the maximum of $2C$ credits has been provided; or no bank is willing to provide any more credit, regardless of its signal. In the latter case, the banks "herd" on declining to provide credit.[18] To see this, suppose that after some history h_{t-1}, bank t declines to provide any credit regardless of its signal. This implies that bank $t+1$ cannot learn anything from bank t's action and is thus in exactly the same situation as bank t. Consequently, bank $t+1$ will also refuse to invest regardless of its signal, and the same is true for all future banks. Because of these related phenomena of *informational cascades* and (*rational*) *herding*, where the available public information swamps the banks' private information and induces them to behave identically, the first stage of the game always ends in finite time in spite of the fact

[18] Banerjee (1992) and Bikhchandani et al. (1992) are the classic references on herding and informational cascades (further references may be found in Neeman and Orosel, 1999). Chari and Kehoe (1997, 2000) describe two herding models that consider crises, but neither is closely related to our analysis. Chari and Kehoe (1997) examine a herding model with an exogenous probability of a fiscal crisis. The government of the borrower country is either "competent" or "incompetent," where being incompetent implies a higher probability to default. The government's type is unobservable to the public, but lenders receive private signals about the likelihood of a crisis. In addition, the borrower country can obtain financing only if N different lenders sequentially agree to collectively provide a large credit. In a crisis the government defaults if and only if it is incompetent. Given the informational assumptions, the possibility of crisis and default makes capital flows excessively volatile, but in contrast to our model, capital flows have no effect on the probability of a crisis. Chari and Kehoe (2000) analyze several variants of a model of herding and financial crisis. However, their model does not distinguish between an international currency crisis and a domestic financial crisis. In contrast, our approach is based on the fact that no creditor enjoys priority in access to foreign reserves. It is this aspect that distinguishes it from a model of domestic bank credits since at the domestic level no similar problem exists. Whereas Chari and Kehoe (2000) examine the effect of an informational externality under different assumptions about lender behavior, our model investigates the effect of the interaction of several external effects that relate to the situation of international banks that finance projects in an emerging market.

that there are no search or inspection costs. Rational herding depends on the assumption that banks' actions do not perfectly reveal the banks' underlying information. This assumption is satisfied if banks use standardized credits or if the details of a credit contract are only imperfectly observed by other banks. Thus, in our context this assumption seems plausible. Moreover, banks have an incentive to hide their private signals, as illustrated by Example 5 below.

Given any specification of the parameters of the model one can, of course, calculate the respective set of perfect Bayesian equilibria. However, due to the interaction of the three external effects that are present in the model we are unable to obtain sharp results on equilibrium behavior in general. Nevertheless we show that it is possible, perhaps surprisingly, to derive general conclusions on efficiency and policy. Before doing so we demonstrate by numerical examples—none of which is based on extreme parameter values—the richness of behavior that is consistent with the notion of pure strategy perfect Bayesian equilibrium. This richness of behavior implies that one should not expect outcomes to be similar across all emerging markets. Rather, even moderate differences in parameter values may have significant effects on equilibrium outcomes.

The numerical examples illustrate that the specific equilibrium outcome depends on the relative strength of the external effects and their interaction. In particular, the interaction of the three external effects generates results that no single external effect could generate on its own.

The first of the numerical examples demonstrates that rational herding may help explain the reason so many banks invest in some particular country or region, whereas other, apparently similar, countries are overlooked.[19] In our model this phenomenon takes the following form: with a high probability either it is the case that two foreign banks invest C each or no foreign banks invest at all. The probability that exactly one foreign bank invests is small. This is due to the informational externality and is illustrated by the following example.

Example 1: Herding. Consider the following stochastic environment: $\Pr(\lambda_L) = \Pr(\lambda_H) = 0.5$, and $\Pr(\theta_1) = 0.01$, $\Pr(\theta_2) = 0.04$, and $\Pr(\theta_3) = 0.95$. The distribution of signals conditional on λ is given by $\Pr(s_U) = 0.25$, $\Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = 0.5$, and $\Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = 0.25$. That is, with probability $\frac{1}{2}$, signals describe the true λ, with probability $\frac{1}{4}$ they are uninformative, and with probability $\frac{1}{4}$ they are misleading. Payoffs are assumed to be $y = -500$, $x_L = -420$, and $x_H = 630$. It is possible to show that a perfect Bayesian equilibrium of this game exists where the probability that at the end of the first stage of the game exactly one bank has invested is only $1/32 = 0.03125$, whereas the probability that two banks have invested is $23/32 = 0.71875$ and the probability that no bank ever invests is $1/4 = 0.25$.

The next example demonstrates that equilibria are not necessarily unique.

Example 2: Pure strategy PBEs are not necessarily unique. Consider the following stochastic environment: $\Pr(\lambda_L) = \Pr(\lambda_H) = 0.5$, and $\Pr(\theta_1) = .05$, $\Pr(\theta_2) = 0.25$, and

[19] See note 5 for empirical evidence.

$\Pr(\theta_3) = 0.7$. The distribution of signals conditional on λ and the payoffs are as in Example 1. It is possible to show that there exists a perfect Bayesian equilibrium where bank 1 invests if and only if $s_1 \in \{s_U, s_H\}$, and if bank 1 has invested (i.e., after the history $h_1 = 1$) bank 2 invests if and only if $s_2 = s_H$. However, there is also another perfect Bayesian equilibrium where bank 1 invests if and only if $s_1 = s_H$, and if bank 1 has invested (i.e., after the history $h_1 = 1$) bank 2 invests if and only if $s_2 \in \{s_U, s_H\}$.

The reason for the non-uniqueness of equilibrium is that in equilibrium one of two banks may act "aggressively," that is, invest even after the uninformative signal, whereas the other bank may act "cautiously," that is, invest only after the high signal. If the first bank acts cautiously, investment reveals that it has observed a high signal, and that allows the second bank to act aggressively. Moreover, given that the second bank acts aggressively, the first bank is forced to act cautiously. On the other hand, if the first bank acts aggressively, the act of investment reveals less favorable information (as it reveals only that the first bank has observed either the high or the uninformative signal) and thus the second bank is forced to act cautiously.[20]

If a foreign bank has already invested, a second bank will invest if and only if it expects a positive expected payoff from doing so. By assumption, every foreign bank that invests receives the same payoff. Therefore, unless the act of investment of the second bank is triggered by some additional information, the first bank to invest cannot be deterred from investment by the knowledge that it will be followed by another foreign bank that will invest after it. However, typically the act of investment *is* triggered by some additional information. This may give rise to a "first mover's curse" that may deter investment altogether. We demonstrate this in the following example.

Example 3: "First Mover's Curse" may prevent investment. Consider the same stochastic environment and distribution of signals conditional on λ as in Example 2. Suppose that payoffs are given by $y = -600$, $x_L = -420$, and $x_H = 630$. It is possible to verify that with these parameters, there exists a unique perfect Bayesian equilibrium. In this equilibrium no bank ever invests, regardless of its signal, in spite of the fact that $E[\pi(1, C, \omega) \mid s_H] = 60 > 0$.

We explain the fact that no bank provides credit in equilibrium in terms of what we refer to as the "first mover's curse." In the example, because $E[\pi(1, 2C, \omega) \mid s_1 = s_2 = s_H] = 12$ and $E[\pi(1, 2C, \omega) \mid s_1 = s_H, s_2 = s_U] = -72$, if the first bank revealed it has observed a high signal, the second bank has an incentive to invest if and only if it has observed a high signal too. The payoffs in the example are such that $E[\pi(1, C, \omega) \mid s_1 = s_H] = 60$ and $E[\pi(1, C, \omega) \mid s_1 = s_U] = -71.25$, so if the first bank knew that no other bank will ever invest after it, then it would like to invest if and only if it observed a high signal. Thus, investment of the first bank reveals that it has observed a high signal. Consequently, the second bank invests whenever the first bank invested and the second bank observed a high signal. Because of the payoff externality, this reduces the payoff of the first bank from 60

[20] This argument shows that the multiplicity of equilibrium is not due to the particular information structure. Uniqueness of equilibrium cannot be ensured even with continuous spaces of states and signals.

when no other bank invests to 12. But since the first bank's expected payoff conditional on its own high signal and on a low or uninformative signal of the second bank (which in this case does not invest) is $E[\pi(1, C, \omega) \mid s_1 = s_H, s_2 \in \{s_L, s_U\}] = -15$, the first bank's expected payoff from investing after observation of the high signal is negative when it anticipates the behavior of the second bank (which will invest if and only if it observes a high signal). It is given by

$$\begin{aligned} & E[\pi(1, \gamma, \omega) \mid s_1 = s_H] \\ = & \Pr(s_2 = s_H \mid s_1 = s_H) \times 12 + \Pr(s_2 \in \{s_L, s_U\} \mid s_1 = s_H) \times (-15) \\ = & -3.75. \end{aligned}$$

In a sense, the first mover's curse is reminiscent of the winner's curse in auctions. In both situations, the value of the object conditional on the private signal and other players' strategies is lower than the expected value of the object conditional on the private signal alone.[21] Moreover, since signals are private information, the first bank cannot wait and postpone its decision until it observes the second bank's signal.

The "perversity" of the first mover's curse described in the previous example may in turn give rise to a phenomenon were the unexpected arrival of unfavorable public information about the profitability of investments may deter future banks and therefore actually encourage investment of the first bank. We demonstrate this in the next example.

Example 4: Unfavorable public information may encourage investment. Consider the following stochastic environment: $\Pr(\lambda_L) = \Pr(\lambda_H) = 0.5$. Suppose that in the absence of a public signal $\Pr(\theta_1) = 0.25$, $\Pr(\theta_2) = 0.15$, and $\Pr(\theta_3) = 0.6$, whereas after the unexpected public signal is realized, all players' change their assessments to $\Pr(\theta_1) = 0.3$, $\Pr(\theta_2) = 0.2$, and $\Pr(\theta_3) = 0.5$. That is, the probability of a currency crisis increases in the sense of first order stochastic dominance. The distribution of signals conditional on λ is identical to what it was in the previous examples and is given by $\Pr(s_U) = 0.25$, $\Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = 0.5$, and $\Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = 0.25$. Finally, payoffs are given by $y = -600$, $x_L = -420$, and $x_H = 630$. In the absence of the public signal, there exists a unique perfect Bayesian equilibrium in which no bank ever invests (as in Example 3). However, it is possible to verify that after the unexpected public information is revealed, there exists a unique perfect Bayesian equilibrium in which bank 1 invests if and only if $s_1 = s_H$, and no other bank ever invests. The reason for this "perverse" effect of public information is that it eliminates the incentive of the second bank to invest after it has observed a high signal and, in addition, has inferred that the first bank has observed a high signal as well. In other words, the unfavorable public information encourages investment because it eliminates the first mover's curse. Obviously, a tax could have the same effect.

As in standard herding models, in the model considered here, only actions (as opposed to private signals) may be observed by future banks. However, one may think it plausible

[21] See Neeman and Orosel (1999) for an analysis of the combined effect of herding and the winner's curse.

that once credit is provided, the details of the credit contract may reveal, perhaps even perfectly, the bank's private signal. Thus, a different model may be considered, one where when credit is given, the private signal is perfectly revealed, and when credit is denied, the private signal remains undetected. The main difference between such an alternative model and ours is that in the former it is possible to show that a unique equilibrium exists. All other results, especially those about the inefficiency of the equilibrium discussed in the next section, remain unchanged (provided the private signal remains undetected when credit is denied). Furthermore, in such an alternative model, the presence of the negative payoff externality implies that banks have an incentive to try to hide their private signals. It is precisely this incentive that motivates our assumption that the act of providing credit does not reveal a bank's private signal. The existence of this incentive is demonstrated in the next example.

Example 5: Incentives to hide the private signal. Consider the following stochastic environment: $\Pr(\lambda_L) = \Pr(\lambda_H) = 0.5$, and $\Pr(\theta_1) = 0.1$, $\Pr(\theta_2) = 0.3$, and $\Pr(\theta_3) = 0.6$. The distribution of signals conditional on λ is identical to what it was in the previous examples. The payoffs are again given by $y = -600$, $x_L = -420$, and $x_H = 630$. If investment reveals the signal perfectly, there is a unique perfect Bayesian equilibrium. In this equilibrium bank 1 invests if and only if $s_1 \in \{s_U, s_H\}$; and if bank 1 has invested after observation of $s_1 = s_H$ (thereby revealing, by assumption, that it has observed a high signal), bank 2 invests if and only if $s_2 = s_H$. If only the actions can be observed, there is also a unique perfect Bayesian equilibrium. In this equilibrium bank 1 invests if and only if $s_1 \in \{s_U, s_H\}$, and no other bank ever invests if bank 1 has invested. Conditional on $s_1 \neq s_H$, the expected payoff of bank 1 is the same in both equilibria, but conditional on $s_1 = s_H$ the expected payoff of bank 1 is 64.5 in the first equilibrium (where investment reveals that bank 1 has observed the high signal), but 192 in the second equilibrium (where only the actions can be observed). Obviously, bank 1 is better off in the second equilibrium and thus has an incentive to hide its private signal. Intuitively, because of the negative payoff externality the bank that invests first does not want other banks to invest after it. Thus, it has an incentive to hide a high signal realization. Since it cannot selectively hide a high signal realization but reveal an uninformative signal realization, it is better off when its signal is not perfectly revealed by its action.[22]

The examples of this section illustrate how the different externalities that we consider interact. Without the payoff externality banks have no incentive to hide their signals, and if they reveal their signals the informational externality vanishes. Moreover, the equilibrium would be unique. The first mover's curse, in turn, shows how the payoff externality interacts with sequential private information. As a consequence of this interaction, bad news or taxes may encourage investment.

[22] A frequent critique that is raised against herding models is that in many of these models agents have no reason to keep their private signals secret, while revealing their signals would increase efficiency. As the preceding example illustrates, this critique does not apply in our case since it is clearly not in a bank's interest to truthfully reveal its signal realization.

4. Efficiency

In this section we show that the perfect Bayesian equilibria of the game are generally inefficient. Sometimes too little credit is provided (as in Example 3 above), but mostly too many credits are provided too easily.

Let $W : \{0, C, 2C\} \times \Omega \to \mathbb{R}$ describe the social welfare associated with supplying a total number of $\gamma \in \{0, C, 2C\}$ credits when the state of the world is given by $\omega \in \Omega$. We assume that,

$$W(\gamma, \omega) = \begin{cases} 0 & \text{if no credits are provided} \\ Y_1 & \text{if } C \text{ credits are provided and a currency crisis occurs} \\ Y_2 & \text{if } 2C \text{ credits are provided and a currency crisis occurs} \\ \frac{\gamma}{C} X_L & \text{if no currency crisis occurs but the projects mostly fail} \\ \frac{\gamma}{C} X_H & \text{if no currency crisis occurs and the projects mostly succeed} \end{cases}$$

where $Y_2 \leq Y_1 < 0$ and $X_L < 0 < X_H$. The assumption that $Y_2 \leq Y_1$ reflects the fact that if more credits have been provided, more capital is lost and more projects have to be terminated once a currency crisis occurs. The fact that X_L and X_H are multiplied by $\gamma/C \in \{0, 1, 2\}$ is due to the fact that the *number* of credits provided affects the extent of both the losses and gains if a currency crisis does not occur. In addition, we assume that $E[W(2C, \omega) - W(C, \omega) \mid \lambda_L] < 0$. That is, conditional on project failure, social welfare decreases if a second bank invests.[23]

Our assumptions about the social welfare function are weak and plausible. Although social objectives may be very different from the banks' private objectives, they need not necessarily be in conflict with one another (which would a priori preclude a socially optimal equilibrium outcome). An example for a social welfare function that satisfies our assumptions is the one where social welfare is proportional to the collective payoff to the foreign banks, perhaps because borrowers and lenders share the benefits of the credit relationship in constant proportions. In this case, $W(\gamma, \omega) = K \frac{\gamma}{C} \pi(1, \gamma, \omega)$ for some constant $K > 0$. Maximization of this particular social welfare function is equivalent to maximization of the foreign banks' total expected payoffs. It follows that there is no intrinsic conflict between the banks' objectives and social welfare.

As a welfare benchmark, consider the best outcome that can be achieved when each bank maximizes the social welfare function W subject to its information constraint and all other banks' strategies.[24] Specifically, we look at the modified game in which the objective function of each bank is to maximize social welfare (but banks' actions may still depend only on their own signals and the observed history of actions). In this modified game we consider the best outcome, in terms of the social welfare function, that can be achieved as a perfect

[23] Notice that this assumption is equivalent to the following inequality being satisfied. $E[W(2C, \omega) - W(C, \omega) \mid \lambda_L] = \Pr(\theta_1)(Y_2 - Y_1) + \Pr(\theta_2)(Y_2 - X_L) + \Pr(\theta_3) X_L < 0$. It can be immediately verified that the inequality is satisfied if $Y_2 \leq X_L$ and $\Pr(\theta_3) > 0$, which is very plausible.

[24] Equivalently, this outcome is the one that a hypothetical social planer who maximizes social welfare can implement under the information constraints of the model.

Bayesian equilibrium. We define this outcome to be the *efficient* outcome.[25] The efficient outcome is a benchmark standard against which we can assess the equilibrium outcome and the outcomes that can be obtained by employing certain policy instruments. However, when conceiving policy measures, incentive constraints have to be taken into account in addition to the information constraints.

Strategies that induce the efficient outcome are called *efficient* strategies. A pure strategy PBE (of the original game) is *efficient,* if it induces the same expected social payoff as the efficient outcome.

The following example confirms the intuition that in equilibrium too many credits may be given too easily.

Example 6: Too many credits are provided too easily. Consider the following stochastic environment: $\Pr(\lambda_L) = 0.25$, $\Pr(\lambda_H) = 0.75$, $\Pr(\theta_1) = 0.1$, $\Pr(\theta_2) = 0.2$, and $\Pr(\theta_3) = 0.7$. The distribution of signals conditional on the state of the world λ is given by $\Pr(s_U) = 0.25$, $\Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = 0.75$, and $\Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = 0$. That is, with probability $\frac{3}{4}$ signals fully reveal whether the projects are mostly successful or not, and with probability $\frac{1}{4}$ they are uninformative. Suppose that payoffs to the foreign banks are given by $y = -500$, $x_L = -420$, $x_H = 630$, and social welfare payoffs are given by $Y_1 = -1000$, $Y_2 = -2000$, $X_L = -840$, and $X_H = 1260$. That is, $W(\gamma, \omega) = 2\frac{\gamma}{C}\pi(1, \gamma, \omega)$, $\gamma \in \{0, C, 2C\}$. It is possible to show that the following profile of strategies achieves efficiency: (i) after any history h_{t-1} such that no bank has ever invested yet, bank t invests if and only if $s_t = s_H$; (ii) after any history h_{t-1} such that bank $t-1$ is the first bank that invested, bank t invests if and only if $s_t \in \{s_U, s_H\}$ (because the fact that bank $t-1$ invested reveals that it has observed the high signal s_H to bank t). Notice that along the play path, since high and low signals are perfectly informative, the fact that bank $t-1$ observed a high signal implies that bank t must observe either a high or an uninformative signal and will therefore invest with probability 1.

However, it is also possible to show that in this example the unique perfect Bayesian equilibrium has the following properties: bank 1 invests if and only if $s_1 \in \{s_U, s_H\}$; bank 2 invests if and only if bank 1 has invested (i.e., $a_1 = 1$) and $s_2 \in \{s_U, s_H\}$; and no other bank ever invests. Notice that when $\lambda = \lambda_H$, $2C$ credits are already provided by the second period, but that this may also happen when $\lambda = \lambda_L$ if both the first two banks observe the uninformative signal (which has conditional probability $\frac{1}{16}$). Moreover, when $\lambda = \lambda_L$, at least the first bank invests whenever it observes the uninformative signal (which has conditional probability $\frac{1}{4}$).

It is straightforward to see that the equilibrium strategies are different from the efficient strategies and that credits are provided too easily in equilibrium relative to the efficient outcome. In particular, bank 1 and bank 2 both invest after the signal realization $s_1 = s_2 = s_U$, whereas according to the efficient strategies neither of them should invest given

[25] Note that the efficient outcome may involve herding as banks may herd on denying credit, and that they may do so in spite of the fact that the (unknown) state of the world would justify the provision of additional credit and that collecting and revealing more signals (as opposed to *actions*) could indicate that this is indeed the case.

these respective signals. To see the intuition, note that if $\lambda = \lambda_H$, a bank will observe the high signal s_H with probability 1 in finite time, whereas no bank will ever observe the low signal s_L. Consequently, in order to achieve the efficient outcome no credits should be provided until a bank observes the high signal s_H.[26] In contrast, in any equilibrium a bank will invest whenever the expected payoff from doing so is positive and thus will invest, in the example, even after the uninformative signal s_U. Whereas efficiency requires collecting more information upon observation of the uninformative signal s_U, from any individual bank's perspective, collecting more information implies it relinquishes its profit opportunity to another bank.

Although Example 6 illustrates an important case, it is clear from the first mover's curse that sometimes too little credit will be provided in equilibrium as well. In fact, a conclusion that international banks provide too much credit everywhere would be problematic on both theoretical and empirical grounds. Banks have to refinance themselves and cannot provide "too many" credits to *all* creditors; and casual evidence does not give the impression that all emerging markets are drowned with cheap capital by private foreign banks. The inefficiency which the externalities of our model generate is not so simple that it can be characterized by a statement like "banks provide too many credits." Rather, banks provide too many credits in some regions and too few in others. Whereas too many credits may precipitate a currency crisis in one region, an inefficient lack of credits may be harmful in preventing or aborting an economic take-off in another region.

The presence of the information externality implies that the problem of identifying the efficient strategies is a difficult one. Since there are three signals but only two actions, the banks' actions cannot always be made to reveal their signals. In addition, only "two shots" are available, since the first stage of the game ends after two banks have invested. Notice that with strategies that are monotone non-decreasing in the banks' signals, at most two high signal realizations can be detected, one through inference and one from direct observation, before the first stage of the game ends.[27] When searching for an efficient strategy, bank t has to consider not only what the best action after the history h_{t-1} and its observed signal s_t is, but also the informational content of its action that can be used by future banks. Consequently, a bank's strategy may be optimal not because of its "direct" consequences for the expected social payoff but because it facilitates the revelation of a particular signal realization to future banks. As the next example demonstrates, sometimes this informational externality may imply that the efficient strategies are not even monotone non-decreasing in the banks' own signals.

[26] As a consequence, the first stage of the game will never end in this example if the efficient strategies are played and $\lambda = \lambda_L$, because in this case, no bank will ever receive the signal s_H. But if we substitute $\Pr(s_L|\lambda_H) = \Pr(s_H|\lambda_L) = 0$ by $\Pr(s_L|\lambda_H) = \Pr(s_H|\lambda_L) = \varepsilon$ for some small positive ε, we get efficient strategies that are basically analogous. The main difference is that if no bank has invested for a certain number of periods, no bank will ever invest and the first stage of the game ends. Another possibility would be to introduce discounting or small inspection costs. Note that in both of these alternative models there is a small probability of making a "mistake" from the ex-post perspective.

[27] Detection of a high signal realization s_H is possible if and only if the bank that invested first had the strategy to invest if and only if it observed s_H.

Example 7: Efficient strategies need not be monotone non-decreasing in the banks' private signals. Consider the following stochastic environment: $\Pr(\lambda_L) = \frac{2}{3}$, $\Pr(\lambda_H) = \frac{1}{3}$, $\Pr(\theta_1) = 0$, $\Pr(\theta_2) = \frac{1}{12}$, and $\Pr(\theta_3) = \frac{11}{12}$. The distribution of signals conditional on λ is given by $\Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = \frac{2}{3}$, and $\Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = \frac{1}{3}$. That is, the probability of the uninformative signal is zero. A signal points to the true state of the world λ with probability $\frac{2}{3}$, and is misleading with the complementary probability. Suppose that payoffs are given by $Y_2 = -1320$, $X_L = 0$, and $X_H = 180$.[28] Notice that since $\Pr(\theta_1) = 0$, the value of Y_1 is irrelevant, and more importantly, a crisis occurs with a positive probability if and only if at least two banks invest. The payoffs and probabilities in his example are chosen such that conditional on two high signals, having only one bank invest is optimal, but conditional on three high signals, having two banks invest is optimal. To see this, consider the following table (where I denotes information, i.e. signal events):

I	$\Pr(\lambda_L \mid I)$	$\Pr(\lambda_H \mid I)$
s_H	$\frac{1}{2}$	$\frac{1}{2}$
$s_H \wedge s_H$	$\frac{1}{3}$	$\frac{2}{3}$
$s_H \wedge s_H \wedge s_H$	$\frac{1}{5}$	$\frac{4}{5}$

Table 1

Conditional on two high signals, having a second bank invest decreases total expected welfare from $E[W(C,\omega) \mid s_1 = s_2 = s_H] = \left(\frac{2}{3}\right)180 = 120$ to $E[W(2C,\omega) \mid s_1 = s_2 = s_H] = \left(\frac{1}{12}\right)(-1320) + \frac{11}{12} \times \left(\frac{2}{3}\right) \times 2 \times 180 = 110$, whereas conditional on three high signals, having a second bank invest increases total expected welfare from $E[W(C,\omega) \mid s_1 = s_2 = s_3 = s_H] = \left(\frac{4}{5}\right)180 = 144$ to $E[W(2C,\omega) \mid s_1 = s_2 = s_3 = s_H] = \left(\frac{1}{12}\right)(-1320) + \frac{11}{12} \times \left(\frac{4}{5}\right) \times 2 \times 180 = 154$. Now, with monotone non-decreasing strategies at most two high signal realizations can be detected before the first stage of the game ends and thus with such strategies it can never be efficient for a second bank to invest. Consequently, it is straightforward to verify that with monotone non-decreasing strategies, expected welfare is maximized when the first bank invests regardless of its signal, which yields an expected social payoff of $\left(\frac{1}{3}\right)180 = 60$.[29]

The following argument demonstrates that it cannot be efficient for all strategies to be monotone non-decreasing. Consider the following alternative strategies: (i) if no bank has

[28] The fact that $X_L = 0$ (which violates our assumptions about the social welfare function W), simplifies the calculations but is not crucial. The same result holds if $X_L < 0$ and $|X_L|$ is small. Similarly, $\Pr(s_U)$ could be positive.

[29] Note that this yields a higher expected welfare than if the first bank invests only if it observed a high signal which is equal to $\left(\frac{1}{3}\right)\left(\frac{2}{3}\right)180 = 40$.

invested up to $t-1$, bank t invests if and only if $s_t = s_L$; (ii) if one bank has invested before $t-1$, bank t invests if and only if $s_t = s_H$ and, in addition, the expected marginal payoff from doing so is positive, that is, $E\left[W\left(2C,\omega\right) - W\left(C,\omega\right) \mid h_{t-1}, s_t = s_H\right] > 0$. According to this policy, (a) with probability 1 at least one bank invests; and (b) because a high and a low signal "cancel" each other, and the event that the first three or more observed signals are high has a positive probability, then with a positive probability a second bank invests after four or more high signals and one low signal which increases expected welfare beyond what is obtained when only one bank invests. It follows that the expected welfare from this policy is strictly larger than 60.

It is important to note that although efficient strategies may not be monotone non-decreasing, strategies that are not monotone non-decreasing are not compatible with the incentive constraints that self-interested banks impose on any policy maker. Under a profile of strategies that are not monotone non-decreasing, a bank may be asked to provide credit if it observed an unfavorable signal, but is prevented from providing credit if it observed a more favorable signal. The reason why this may be optimal is that the bank is "sacrificed" so that the fact that it observed a particularly unfavorable signal becomes public information and, perhaps more importantly, it allows to "signal" the observation of a high signal when the bank declines to invest, allowing for a large number of high signals to be successively signaled in this way. It is unlikely that banks will agree to sacrifice themselves, neither is it likely that any international body will agree to subsidize such sacrifice for all the moral hazard problems it would raise.

The possibility that the efficient strategies are not monotone non-decreasing prevents us from obtaining a full characterization of efficient strategies and outcomes. However, from a policy point of view it is more interesting to characterize the strategies that maximize social welfare under the additional constraint of incentive compatibility, and thus under the additional constraint that the strategies have to be monotone non-decreasing. The following proposition provides such a characterization.

Proposition 2. *Among all monotone non-decreasing strategies, the ones that maximize social welfare are such that bank t invests if and only if less than $2C$ credits have been provided so far, it observed the highest possible signal $s_t = s_H$, and its investment increases the expected social welfare conditional on the history and the observed signal $s_t = s_H$.*

It follows that if the efficient strategies happen to be monotone non-decreasing, then they must coincide with the strategies described in the previous proposition. We are also able to identify a general set of situations where efficient strategies *are* monotone non-decreasing.

Proposition 3. *Suppose that by some time t, either C credits have already been given, or it has become clear that no more than C credits will ever be given. Then, as of time $t+1$ onwards, efficient strategies are monotone non-decreasing. In the former case, until $2C$*

credits have been provided the efficient strategies are given by

$$\sigma^*(h_{\tau-1}, s_\tau) = \begin{cases} 1 & \text{if } s_\tau = s_H \text{ and} \\ & E\left[W(2C,\omega) - W(C,\omega) \mid \left\{(\sigma_j,\beta_j)\right\}_{j=1}^{\tau-1}, h_{\tau-1}, s_\tau = s_H\right] > 0 \\ 0 & \text{otherwise} \end{cases}$$

for every $\tau = t+1, t+2, \ldots$ In the latter case, until C credits have been provided the efficient strategies are given by

$$\sigma^*(h_{\tau-1}, s_\tau) = \begin{cases} 1 & \text{if } s_\tau = s_H \text{ and } E\left[W(C,\omega) \mid \left\{(\sigma_j,\beta_j)\right\}_{j=1}^{\tau-1}, h_{\tau-1}, s_\tau = s_H\right] > 0 \\ 0 & \text{otherwise} \end{cases}$$

for every $\tau = t+1, t+2, \ldots$ Furthermore, there exists a finite number K such that in both cases, either C additional credits are provided by time $t+K$, or the first stage of the game ends.

We note that the situation where by some time t it becomes clear that no more than C credits ought to be provided may be interpreted as one where investment is not very attractive to begin with, perhaps because the probability of a currency crisis is quite high.[30]

Finally, we note that since PBE strategies are non-decreasing (Proposition 1), a PBE may be efficient only if banks provide credit only after they have observed the best possible signal $s = s_H$. However, while investing only after observing the best possible signal is necessary for efficiency, it is not sufficient. Even if banks provide credit only after observing the best possible signal, PBEs are still likely to be inefficient because the banks require in addition that their expected profits from providing credit are positive, whereas efficiency requires that expected social welfare is increased. In particular, the second bank to invest does not take into account the negative payoff externality it imposes on the bank that has already invested. The difference between these two criteria is likely to imply the inefficiency of any PBE even if banks invest only after observing the best possible signal.

5. Policy

While socially efficient profiles of strategies may be identified, self-interested international banks will not implement these strategies unless it is optimal for them to do so. In this section we pose the question of whether there exists a "simple" policy that increases social welfare. We assume that the policy maker can only rely on taxes and subsidies on short-term foreign credits to induce or discourage investments. Specifically, we assume that at any time $t \geq 1$ the policy maker can impose a tax $z_t = z(h_{t-1})$ (or a subsidy when $z_t < 0$) on bank t if it invests.[31] The tax z_t may depend on the publicly observed history h_{t-1} but

[30] This may be the case if, for example, even when $\lambda = \lambda_H$ no more than C credits ought to be provided because the probability of a currency crisis is too high when the country receives $2C$ credits.

[31] Exemptions from (future) income taxes and (partial) state guarantees for the credits are in many ways equivalent to a subsidy and are not analyzed separately.

not on the privately observed signals. Banks that do not invest cannot be taxed and receive no subsidies. We assume that the policy maker is capable of committing to a tax scheme $z : \mathcal{H} \to \mathbb{R}$.[32] Given this limited set of instruments, can the policy maker achieve the efficient outcome or at least improve upon the perfect Bayesian equilibrium?[33]

It is important to note that due to the incentive constraints a system of taxes and subsidies can only help in the implementation of bank strategies that are monotone non-decreasing in the banks' private signals. This follows from the fact that for any given tax z_t, whenever the expected gain to bank t from supplying credit after observing a signal $s_t \in \{s_L, s_U\}$ is positive, it is also positive when the bank observes the highest possible signal $s_t = s_H$. Or,

$$E\left[\pi\left(1, C, \omega\right) \mid \left\{\left(\sigma_\tau, \beta_\tau\right)\right\}_{\tau=1}^{\infty}, z, h_{t-1}, s_t = s'\right] - z_t > 0$$

$$\Longrightarrow E\left[\pi\left(1, C, \omega\right) \mid \left\{\left(\sigma_\tau, \beta_\tau\right)\right\}_{\tau=1}^{\infty}, z, h_{t-1}, s_t = s''\right] - z_t > 0$$

for every $s'' > s'$. This has the following implication. Define the *second-best* outcome as the best outcome that can be achieved under the information constraints of the model and the additional constraint that only monotone non-decreasing strategies may be employed by the banks. We have the following proposition.

Proposition 4. *The second-best outcome can be implemented through a sequence of (history dependent) taxes and subsidies.*

Given the richness of behavior that may arise in equilibrium, it is interesting that a simple policy of just taxes and subsidies can in fact achieve so much. The reason is that the tax scheme reacts to the information that can be inferred from the history of actions. For example, it is feasible and may be perfectly rational to subsidize a "first wave" of foreign credits, but to tax a "second wave" (in order to prevent it).[34] Furthermore, it is possible that without taxes or subsidies no bank may invest because of the "first mover's curse" (Example 3). As implied by Example 4, imposing high enough taxes on future banks may eliminate this first mover's curse. Thus, a tax on a "second wave" of investments may trigger a "first wave." In fact, it may be the case that while no investment will occur in equilibrium

[32] Notice that commitment should not be problematic in this context because it is always in the best interest of the policy maker to follow the announced tax scheme.

[33] We do not require (ex ante) budget balancing of the policy. If the policy generates a surplus, other taxes can be reduced and thus there is a "double dividend," similar to the case of a "green tax." If the policy generates a deficit, there is an associated excess burden. A general equilibrium analysis would take these effects into account and we could do so as well (—assuming a constant excess burden per tax dollar, this would be straightforward). However, we think that these effects are quantitatively negligible. Therefore, we ignore them in order to concentrate on the main point.

[34] If the expected social benefit from investing exceeds the bank's expected profit sufficiently, it is rational to subsidize investments that would not occur otherwise. However, if a bank invests when following the second-best strategy, it necessarily reveals a high signal (Proposition 2). This may in turn induce further investment that is not socially optimal and thus should be prevented by a tax.

absent any taxes, the efficient outcome (or the second-best) requires that both the first and later investments are taxed.[35]

As we have seen in the previous section, under some circumstances, namely when the next C credits to be provided are sure to be the last ones, monotone non-decreasing strategies achieve the efficient outcome (Proposition 3). Under such circumstances a system of taxes and subsidies can therefore generate the efficient outcome because such a system can guarantee that banks invest exactly when they observe a high signal and investment increases social welfare conditional on that signal. As noted in the previous section, one particular such case is where the risk of a currency crisis is so "severe" that no more than C credits ought to be provided.

Although by construction the tax scheme depends only on public information, a history dependent tax scheme is no easy task. It requires specialized information and flexibility. This suggests that the central bank should be the institution to implement it. Similar to minimum reserve requirements, the central bank can vary the tax rates according to its information. The tax may even take the form of "special reserve requirements" for short-term capital inflows.

History dependent taxes may nevertheless be regarded as "unrealistic." The model implies that there is still room for beneficial economic policy. For example, the model makes clear that an appropriately chosen upper bound on short-term capital inflows, a judicious tax (or subsidy) on short-term capital inflows that is independent of history, or a combination of these two instruments may improve efficiency, at least in expectation. An alternative route is to encourage the international banks to form a "regulated cartel" in order to internalize the externalities.

Finally, the IMF or the World Bank could assist countries in establishing the optimal tax scheme. Alternatively, these institutions could initiate consortia of private banks, where each consortium provides credits for a particular country or region. As the leader of the consortium, the respective institution should have the contractual right to impose a fee (which may depend on the history of actions and may be negative) on a bank that invests and to redistribute the debtors' payments among the members of the consortium. If the fee scheme maximizes a social welfare function that is not too different from the member banks' expected aggregate profits, an appropriate redistribution scheme will secure each participating bank an ex-ante positive expected profit and thus banks will voluntarily join such a consortium. Since the IMF or the World Bank, respectively, could take interdependencies between countries or regions into account, such a policy of "guided consortia" could be preferable to individual countries imposing tax schemes separately. Moreover, it would leave provision of credits to private banks, whereas it assigns the role of coordination to the IMF or the World Bank. This seems to be an appropriate division of tasks between private and public institutions.

[35] Taxing the second investment makes it unprofitable and thus eliminates the first mover's curse. Having achieved that, taxing the first investment as well may be necessary to prevent investment after observation of only the uninformative signal.

6. Conclusions

The prevalence of currency crises in recent years gives rise to the question of what has caused their repeated occurrence.[36] Some argue that bailout guarantees are the main culprits. Because of these bailout guarantees, creditors neglect to screen out bad projects, too much credit is given and a hidden fiscal deficit is generated. Consequently, the likelihood that a currency crisis occurs increases.[37] Others argue that the blame lies with "crony capitalism" methods that debtor countries adopted when they industrialized or when they liberalized their economies. This, in turn, raises the question of how those countries which adopted crony capitalist methods succeed in obtaining credit in the first place, to which the answer is, again, because foreign lenders can count on being bailed out.

In light of this discussion, the general message of this paper is that in addition to bailout guarantees and weaknesses within the debtor countries the lenders' side also deserves some attention. Our paper should thus be seen as complementary to the rest of the literature. As we show, even if foreign banks cannot count on being bailed out, they may still provide too many credits too easily, which may precipitate the onset of financial crises. Moreover, whereas bailout guarantees unambiguously lead to too many credits, our analysis and the variety of examples that illustrate it, show that the situation is more complicated. Outcomes cannot be expected to be similar across all emerging markets and in particular, inefficiency may result in the provision of too few credits as well. Of course, the provision of too few credits does not generate a currency crisis and thus is less visible. For a country, however, it need not be less harmful.

Finally, we show in Section 5 that a judicious "correction" of the incentives of foreign banks through taxes and subsidies may in fact improve overall efficiency and reduce the likelihood that crises occur. The IMF and the World Bank could play an important role either with technical assistance or as coordinators of consortia of private banks.

[36] Chang and Velasco (1999), for example, mention the following alternative explanations: "The recent literature offers no shortage of villains to blame for the financial crashes in Mexico, East Asia, Russia, and Brazil: corruption and cronyism, lack of transparency and imperfect democracy, misguided investment subsidies and loan guarantees, external deficits that are too large (or sometimes too small), fixed exchange rates that are maintained for too long (or abandoned too readily), poor financial regulation, excessive borrowing abroad—the list goes on and on." (p. 1). Note that although many different causes are listed, they are all attributed to debtor countries' behavior.

[37] Schneider and Tornell (1999) identify a class of models in which government bailout guarantees and moral hazard in financial markets are responsible for currency crises. "Such distortions induce overinvestment in negative [net present value] projects, which creates a hidden fiscal deficit. Since such a deficit is unsustainable, a crisis is inevitable" (p. 4). They cite Corsetti, Pesenti and Roubini (1999), Krugman (1998) and McKinnon and Pill (1998) as examples. In their own model, "bailout guarantees can be a chief culprit in making the economy vulnerable [to a crisis]" (p. 28). Burnside et al. (2002) provide a dynamic model as well as empirical evidence to substantiate their claim that "a principal cause of the 1997 Asian crisis was large prospective deficits associated with implicit bailout guarantees to failing banking systems" (p. 1155). This strain of literature implies that preventing banks from being bailed out may eliminate the risk of a currency crises or at least significantly reduces it.

Acknowledgements and contact information

We are grateful to Dilip Mookherjee, Muriel Niederle, Alex Stomper, and seminar participants at Boston University, the University of Vienna, the University of Zurich, and the Theoretische Ausschuss of the Verein für Socialpolitik, for their comments. An editor of this journal, Kyle Bagwell, and an anonymous referee also provided useful comments. Gerhard Orosel gratefully acknowledges the hospitality of the Weatherhead Center for International Affairs at Harvard University and the support of the Schumpeter Society, Vienna.

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Appendix A: Mathematical Proofs

Proof of Proposition 1. We first prove (ii), then (iii), then (i). Let $\gamma_t = \sum_{i=1}^{t} a_i C \in \{0, C, 2C\}$ denote the number of credits provided to the country by time t. For every t, γ_t is a random variable whose realization depends on the banks strategies and on the realization of banks' signals.

First we show that in every pure strategy PBE banks' strategies are monotone non-decreasing in their signals. The bank that moves at t invests only if

$$E_\omega \left[\pi\left(1, \gamma_t, \omega\right) \mid \left\{\left(\sigma_\tau, \beta_\tau\right)\right\}_{\tau=1}^{T}, h_{t-1}, s_t \right] \geq 0$$

because otherwise $E_{\gamma_T,\omega} \left[\pi\left(1, \gamma_T, \omega\right) \mid \left\{\left(\sigma_\tau, \beta_\tau\right)\right\}_{\tau=1}^{T}, h_{t-1}, s_t \right] < 0$ for all $T \geq t$. Therefore, if bank t invests, $E_{\gamma_T,\omega} \left[\pi\left(1, \gamma_T, \omega\right) \mid \left\{\left(\sigma_\tau, \beta_\tau\right)\right\}_{\tau=1}^{T}, h_{t-1}, s_t \right]$ is non-increasing in T and thus converges for $T \to \infty$ (since π is bounded from below). It follows that bank t invests only if

$$\lim_{T\to\infty} E_{\gamma_T,\omega} \left[\pi\left(1, \gamma_T, \omega\right) \mid \left\{\left(\sigma_\tau, \beta_\tau\right)\right\}_{\tau=1}^{T}, h_{t-1}, s_t \right] \geq 0.$$

It invests for sure whenever the inequality is strict. Suppose there exists some perfect Bayesian equilibrium $\{(\sigma_t, \beta_t)\}_{t=1}^{\infty}$ where for some time t and some history h_{t-1}, the bank that moves at t invests after observing the signal s' but not after observing the better signal s''. Suppose that bank t deviates and invests after observing the signal s''. Its expected payoff is

$$\begin{aligned} & \lim_{T\to\infty} E_{\gamma_T,\omega} \left[\pi\left(1, \gamma_T, \omega\right) \mid \left\{\left(\sigma_\tau, \beta_\tau\right)\right\}_{\tau=1}^{T}, h_{t-1}, s'' \right] \\ > & \lim_{T\to\infty} E_{\gamma_T,\omega} \left[\pi\left(1, \gamma_T, \omega\right) \mid \left\{\left(\sigma_\tau, \beta_\tau\right)\right\}_{\tau=1}^{T}, h_{t-1}, s' \right] \\ \geq & \ 0. \end{aligned}$$

The first inequality above follows from the fact that s'' is a better signal than s', implying a more favorable distribution over ω, and the fact that the banks that move after bank t cannot observe bank t's deviation and therefore do not react to it.[38] The second inequality follows from the fact that $\{(\sigma_t, \beta_t)\}_{t=1}^{\infty}$ is a PBE. Therefore, bank t should invest after observing the signal s''. A contradiction.

We now show that the first stage of the game ends in finite time. That is, there exists a time $T < \infty$ such that $\gamma_{t+1} = \gamma_t$ for every $t \geq T$. If after some history h_t, either two banks have already invested or no bank will invest in the future regardless of the signal it observes, then the first stage of the game has ended. Otherwise, since strategies are monotone non-decreasing, if after a history h_{t-1} bank t does not invest, it must be that the signal it observed, s_t, is either equal to s_L or s_U, which increases the posterior probability that $\lambda = \lambda_L$ and thus decreases the expected payoff that future banks can obtain from investing. It can be verified that there exists a finite number k, such that the posterior expected payoff from investing conditional on observing k bad or uninformative signals and one good signal is negative. Consequently, after k banks decline to invest, no bank will want to invest and the first stage of the game will end.

Finally, existence of a pure strategy PBE follows from the fact that the first stage of the game ends in finite time. A pure strategy PBE exists by backwards induction. ■

Proof of Propositions 2 and 3. The three lemmas below are used in the proofs of Propositions 2 and 3.

Lemma 1. *At any t, it is never efficient to provide a credit independently of the signal s_t.*

Proof. Fix a time t, a history h_{t-1}, and a profile of strategies $\{\sigma_\tau\}_{\tau=1}^{\infty}$. Suppose that under this profile of strategies, the bank that moves at t provides C credits regardless of the signal it observes. We distinguish between two cases: (1) C credits have already been provided by time t, and (2) no credits have been provided by time t.

Consider case (1) first. Denote $r(\omega) = W(2C, \omega) - W(C, \omega)$. Since C credits have already been provided, providing C more credits will end the first stage of the game yielding an additional social surplus of:

$$\begin{aligned} E\left[r(\omega) \mid \{\sigma_\tau\}_{\tau=1}^{t-1}, h_{t-1}\right] &= \Pr\left(\lambda_L \mid \{\sigma_\tau\}_{\tau=1}^{t-1}, h_{t-1}\right) E\left[r(\omega) \mid \lambda_L\right] \\ &\quad + \Pr\left(\lambda_H \mid \{\sigma_\tau\}_{\tau=1}^{t-1}, h_{t-1}\right) E\left[r(\omega) \mid \lambda_H\right]. \end{aligned}$$

Notice that, by assumption, $E[r(\omega) \mid \lambda_L] < 0$. In case $E[r(\omega) \mid \lambda_H] \leq 0$ the conclusion follows immediately, so assume $E[r(\omega) \mid \lambda_H] > 0$. Bayesian updating implies that, for every history h_{t-1},

$$\Pr\left(\lambda_L \mid \{\sigma_\tau\}_{\tau=1}^{t-1}, h_{t-1}, s_t = \cdots = s_{t+k} = s_L\right) \underset{k \nearrow \infty}{\nearrow} 1,$$

[38] Thus, conditional on λ_j, $j \in \{\lambda_L, \lambda_H\}$, bank t assigns the same probability distribution on future banks' actions for s' and s''. Since conditional on λ_H the expected payoff of bank t is positive and is negative conditional on λ_L, the expected payoff of bank t increases in the probability of λ_H, and thus increases when s'' replaces s'.

and

$$\Pr\left(\lambda_H \mid \{\sigma_\tau\}_{\tau=1}^{t-1}, h_{t-1}, s_t = \cdots = s_{t+k} = s_L\right) \underset{k\nearrow\infty}{\searrow} 0.$$

Therefore, there exists a finite integer K such that

$$E\left[r(\omega) \mid \{\sigma_\tau\}_{\tau=1}^{t-1}, h_{t-1}, s_t = \cdots = s_{t+K} = s_L\right] < 0.$$

By assumption, the profile of strategies $\{\sigma_\tau\}_{\tau=1}^{\infty}$ calls for the bank that moves at t to provide credit regardless of its signal. We show that there exists another profile of strategies that generates a higher social surplus, implying that $\{\sigma_\tau\}_{\tau=1}^{\infty}$ cannot be efficient. Specifically, suppose that instead of providing C credits at t regardless of the signal and ending the first stage of the game, the banks follow the following strategies: every bank that moves at time $\tau \in \{t, ..., t+K\}$ provides credit if and only if it observes a signal $s_\tau \in \{s_U, s_H\}$. The banks that move after time $t+K$ do not provide credit regardless of their signal. We show that this new profile of strategies provides a higher expected social surplus than $\sigma = \{\sigma_\tau\}_{\tau=1}^{\infty}$. This follows from the fact that,

$$\begin{aligned}
& E\left[r(\omega) \mid \{\sigma_\tau\}_{\tau=1}^{t-1}, h_{t-1}\right] \\
= \; & \Pr(s_t = \cdots = s_{t+K} = s_L \mid \sigma, h_{t-1})\, E[r(\omega) \mid \sigma, h_{t-1}, s_t = \cdots = s_{t+K} = s_L] + \\
& [1 - \Pr(s_t = \cdots = s_{t+K} = s_L \mid \sigma, h_{t-1})] \times \\
& \qquad E[r(\omega) \mid \sigma, h_{t-1}, s_\tau \neq s_L \text{ for some } \tau \in \{t, ...t+K\}] \\
< \; & [1 - \Pr(s_t = \cdots = s_{t+K} = s_L \mid \sigma, h_{t-1})] \times \\
& \qquad E[r(\omega) \mid \sigma, h_{t-1}, s_\tau \neq s_L \text{ for some } \tau \in \{t, ...t+K\}]
\end{aligned}$$

which is equal to the additional expected social surplus under the new profile of strategies since in contrast to what happens under $\{\sigma_\tau\}_{\tau=1}^{\infty}$, under the new strategies, no credit is provided when $s_\tau = s_L$ for all $\tau \in \{t, ..., t+K\}$.

Consider now case (2). Fix a time t, a history h_{t-1}, and a profile of strategies $\{\sigma_\tau\}_{\tau=1}^{\infty}$. Suppose that no credits have been provided up to time t, and that under this profile of strategies, the bank that moves at t provides C credits regardless of the signal it observes. Under any profile of efficient strategies the first stage of the game must end in finite time with positive probability. Thus, if the profile of strategies $\{\sigma_\tau\}_{\tau=1}^{\infty}$ is efficient, there exists a T such that with positive probability the first stage of the game ends by period $t+T$. Consider the alternative profile of strategies $\{\sigma'_\tau\}_{\tau=1}^{\infty}$, which is defined as follows: (i) for $\tau \in \{1, ..., t-1\}$, $\sigma'_\tau \equiv \sigma_\tau$, i.e., the alternative strategy is identical to the original strategy; (ii) the bank that moves at t does not provide any credit regardless of the signal it observes; (iii) the banks $\tau \in \{t+1, ..., t+T\}$ follow their original strategies σ_τ as if bank t has invested, until according to the original strategy profile the first stage of the game has ended or period $t+T$, whichever comes first; (iv) if according to the original strategy profile the first stage of the game ends with some bank $\tau \in \{t, ..., t+T\}$, bank $\tau+1$ invests regardless of the signal it observes and the first stage of the game ends thereafter; (v) finally, if according to the original strategy profile the first stage of the game has not ended by time $t+T$, bank $t+T+1$ invests regardless of the signal it observes, and $\sigma'_{\tau+1} \equiv \sigma_\tau$ for all $\tau \geq t+T+2$. That is, after bank $t+T$ we "insert" an additional bank that invests regardless of its signal ("instead of" bank t) and this additional bank is ignored by the banks that move later and follow their original strategies. Notice that whenever under the original profile of strategies $\{\sigma_\tau\}_{\tau=1}^{\infty}$ the first stage of the game ends with a bank $\tau \in \{t, ..., t+T\}$, under the alternative strategy profile $\{\sigma'_\tau\}_{\tau=1}^{\infty}$ it ends with bank $\tau+1$, without any difference in the public information obtained. Otherwise play continues identically with a "lag" of one period. Consequently, the expected social payoff is exactly the same under both profiles of strategies, $\{\sigma_\tau\}_{\tau=1}^{\infty}$ and $\{\sigma'_\tau\}_{\tau=1}^{\infty}$. However, from the proof of case (1) it follows that whenever under the profile of strategies $\{\sigma'_\tau\}_{\tau=1}^{\infty}$ the first stage of the game ends with some bank $\tau \in \{t+1, ..., t+T+1\}$, a strictly higher social payoff can be achieved by some alternative (third) profile of strategies. Since the event that under the profile of strategies $\{\sigma'_\tau\}_{\tau=1}^{\infty}$ the first stage of the game ends with some bank $\tau \in \{t+1, ..., t+T+1\}$ has, by construction, a positive probability, this implies that the profile of strategies $\{\sigma'_\tau\}_{\tau=1}^{\infty}$ does not achieve the efficient outcome. But then neither can the original profile of strategies $\{\sigma_\tau\}_{\tau=1}^{\infty}$ be efficient because it generates the same expected payoff as $\{\sigma'_\tau\}_{\tau=1}^{\infty}$. A contradiction. ■

Lemma 2. *After any history h_{t-1}, the following cannot be efficient strategies for bank t: (i) $a_t = 1$ if and only if $s_t = s_U$; and, (ii) $a_t = 1$ if and only if $s_t \in \{s_L, s_H\}$.*

Proof. Notice that the two investment strategies described above are not based on any favorable information and they do not transmit any valuable information into the future. They are thus equivalent to lotteries where C credits are provided with a certain probability, regardless of the signal, and with the complementary probability no credit is given, regardless of the signal. It is then straightforward to see that the previous lemma can be extended to cover this case too. ■

Lemma 3. *After any history h_{t-1} such that the next C credits to be provided will be the last ones (either because C credits have already been provided, or because whatever information is revealed in the future, efficiency requires that no more than C credits be provided* [39]*), the efficient strategy of bank $\tau \geq t$ is monotone non-decreasing in its signal.*

Proof. Assume the condition described in the statement of the lemma is satisfied from time t onwards. By the previous two lemmas, it is enough to show that if for some $\tau \geq t$ an efficient strategy prescribes $a_\tau = 1$ upon observation of $s_\tau = s_L$ it must also prescribe $a_\tau = 1$ upon observation of $s_\tau = s_H$.

Let $\sigma = (\sigma_1, \sigma_2, ...)$ denote a profile of efficient strategies. Suppose that for some $\tau \geq t$, $\sigma_\tau(h_{\tau-1}, s_L) = 1$ but $\sigma_\tau(h_{\tau-1}, s_H) = 0$. We show that there exists another profile of strategies, denoted σ', that generates a strictly higher expected social surplus, implying a contradiction. The profile of strategies σ' is defined as follows: it coincides with σ everywhere, except that $\sigma'_\tau(h_{\tau-1}, s_L) = 0$, and $\sigma'_\tau(h_{\tau-1}, s_H) = 1$. Let $P = E[W(\gamma, \omega) \mid \sigma, h_{t-1}]$ denote

[39] This may be the case, for example, if even when it is known that $\lambda = \lambda_H$, efficiency implies that no more than C credits ought to be provided because the probability of a currency crisis is too high when the country receives $2C$ credits.

the expected social welfare under σ conditional on h_{t-1}, and let $P' = E[W(\gamma, \omega) \mid \sigma', h_{t-1}]$ denote the expected social welfare under σ' conditional on h_{t-1}. In these expectations, γ denotes the random number of credits that are being supplied at the end of the first stage of the game conditional on the history h_{t-1} and the strategy profile σ and σ', respectively. Finally, let $\overline{\gamma}$ denote the maximum number of credits that may be given. That is, $\overline{\gamma} = 2C$ if C credits have already been given by t, and $\overline{\gamma} = C$ if no credits have been given by t. Notice that with slight abuse of notation, P can be written as,

$$\begin{aligned} P \;=\; & \Pr(s_H \mid \lambda_L) \Pr(\lambda_L \mid h_{t-1}) E[W(\gamma, \omega) \mid \sigma, \lambda_L] \\ & + \Pr(s_U \mid \lambda_L) \Pr(\lambda_L \mid h_{t-1}) E[W(\gamma, \omega) \mid \sigma, \lambda_L] \\ & + \Pr(s_L \mid \lambda_L) \Pr(\lambda_L \mid h_{t-1}) E[W(\overline{\gamma}, \omega) \mid \lambda_L] \\ & + \Pr(s_H \mid \lambda_H) \Pr(\lambda_H \mid h_{t-1}) E[W(\gamma, \omega) \mid \sigma, \lambda_H] \\ & + \Pr(s_U \mid \lambda_H) \Pr(\lambda_H \mid h_{t-1}) E[W(\gamma, \omega) \mid \sigma, \lambda_H] \\ & + \Pr(s_L \mid \lambda_H) \Pr(\lambda_H \mid h_{t-1}) E[W(\overline{\gamma}, \omega) \mid \lambda_H], \end{aligned}$$

and that P' can be written as,

$$\begin{aligned} P' \;=\; & \Pr(s_H \mid \lambda_L) \Pr(\lambda_L \mid h_{t-1}) E[W(\overline{\gamma}, \omega) \mid \lambda_L] \\ & + \Pr(s_U \mid \lambda_L) \Pr(\lambda_L \mid h_{t-1}) E[W(\gamma, \omega) \mid \sigma, \lambda_L] \\ & + \Pr(s_L \mid \lambda_L) \Pr(\lambda_L \mid h_{t-1}) E[W(\gamma, \omega) \mid \sigma, \lambda_L] \\ & + \Pr(s_H \mid \lambda_H) \Pr(\lambda_H \mid h_{t-1}) E[W(\overline{\gamma}, \omega) \mid \lambda_H] \\ & + \Pr(s_U \mid \lambda_H) \Pr(\lambda_H \mid h_{t-1}) E[W(\gamma, \omega) \mid \sigma, \lambda_H] \\ & + \Pr(s_L \mid \lambda_H) \Pr(\lambda_H \mid h_{t-1}) E[W(\gamma, \omega) \mid \sigma, \lambda_H]. \end{aligned}$$

Consequently,

$$\begin{aligned} & P' - P \\ = \; & [\Pr(s_H \mid \lambda_L) - \Pr(s_L \mid \lambda_L)] \Pr(\lambda_L \mid h_{t-1}) \{E[W(\overline{\gamma}, \omega) \mid \lambda_L] - E[W(\gamma, \omega) \mid \sigma, \lambda_L]\} \\ & + [\Pr(s_H \mid \lambda_H) - \Pr(s_L \mid \lambda_H)] \Pr(\lambda_H \mid h_{t-1}) \{E[W(\overline{\gamma}, \omega) \mid \lambda_H] - E[W(\gamma, \omega) \mid \sigma, \lambda_H]\}. \end{aligned}$$

Observe that,

$$E[W(\overline{\gamma}, \omega) \mid \lambda_L] - E[W(\gamma, \omega) \mid \sigma, \lambda_L] \leq 0$$

because $\gamma \leq \overline{\gamma}$ and when $\lambda = \lambda_L$ it is better to provide as few credits as possible; and

$$E[W(\overline{\gamma}, \omega) \mid \lambda_H] - E[W(\gamma, \omega) \mid \sigma, \lambda_H] \geq 0$$

because $\gamma \leq \overline{\gamma}$ and when $\lambda = \lambda_H$ it is better to provide as many credits as possible. Furthermore, since it cannot be that under an efficient strategy, C additional credits are provided after t with probability 1 and hence the upper bound $\overline{\gamma}$ is always achieved, at least one of the two inequalities above must be strict. Finally, the fact that, by assumption, both $\Pr(s_H \mid \lambda_L) < \Pr(s_L \mid \lambda_L)$, and $\Pr(s_H \mid \lambda_H) > \Pr(s_L \mid \lambda_H)$, implies that $P' > P$. A contradiction. ■

We prove Proposition 3 before 2.

Proof of Proposition 3. We prove the Proposition for the case where after some history h_{t-1}, it becomes known that no more than C credits will ever be provided. The proof for the other case is analogous. Let $\sigma = (\sigma_1, \sigma_2, ...)$ denote a profile of efficient strategies. The previous three lemmas imply that we only have to show that there does not exist some $\tau \geq t$, where at τ a bank provides C credits after observing the uninformative signal s_U. Suppose then that $\tau \geq t$ is the last bank that optimally provides C credits upon observation of the uninformative signal s_U under σ. By assumption, all the banks that move after τ, provide credit only upon observation of the highest possible signal s_H, if at all. Such a last bank exists because the monotonicity of banks' efficient strategies implies that for all large enough t,

$$E\left[W\left(C,\omega\right) \mid \sigma, a_1 = \cdots = a_{t-1} = 0, s_t = s_U\right] \leq 0,$$

and it cannot be efficient that bank t provides credit in such circumstances.[40]

We show that a profile of strategies, denoted σ', that coincides with σ up to $\tau - 1$, and from τ onwards is identical to the one described in the statement of the proposition and where bank τ provides C credits only upon observation of the highest possible signal s_H generates a higher expected social welfare than σ. Let K^* denote the smallest integer number such that the bank moving at $\tau + K^* + 1$ would not provide C credits (provided none were provided before) even if it observes the highest possible signal s_H under σ. That is, K^* is the smallest integer number such that

$$\begin{aligned} & E\left[W\left(C,\omega\right) \mid \sigma, h_{\tau-1}, a_\tau = \cdots = a_{\tau+K^*} = 0, s_{\tau+K^*+1} = s_H\right] \\ = \; & E\left[W\left(C,\omega\right) \mid \sigma, h_{\tau-1}, s_\tau = s_L, s_{\tau+k} \in \left\{s_L, s_U\right\} \; \forall k \in \left\{1,...,K^*\right\}, s_{\tau+K^*+1} = s_H\right] \\ \leq \; & 0. \end{aligned}$$

Note that $K^* \geq 1$.[41]

We let K' denote the analog to K^* under σ'. That is, K' is the smallest integer such that,

$$\begin{aligned} & E\left[W\left(C,\omega\right) \mid \sigma', h_{\tau-1}, a_\tau = a_{\tau+1} = \cdots = a_{\tau+K'} = 0, s_{\tau+K'+1} = s_H\right] \\ = \; & E\left[W\left(C,\omega\right) \mid \sigma', h_{\tau-1}, s_{\tau+k} \in \left\{s_L, s_U\right\} \; \forall k \in \left\{0,...,K'\right\}, s_{\tau+K'+1} = s_H\right] \\ \leq \; & 0. \end{aligned}$$

[40] Investment upon observation of the uninformative signal s_U in spite of a non-positive payoff can only be efficient if it is important to "warn" future banks of the worst possible signal s_L in the following way: If bank t does not invest, it reveals that it observed the signal s_L and this, in turn, conveys such "bad news" that no future bank should ever invest, regardless of its observed signal. However, since the signals s_H and s_L cancel each other, if a bank should not invest after the sequence (s_L, s_H) it should also not invest after s_U because the updated probabilities are identical.

[41] This is due to the fact that by assumption,

$$E\left[W\left(1,\omega\right) \mid \sigma, h_{\tau-1}, s_\tau = s_L, s_{\tau+1} = s_H\right] \;=\; E\left[W\left(1,\omega\right) \mid \sigma, h_{\tau-1}, s_\tau = s_U\right] \;>\; 0.$$

The difference between K' and K^* is that in the definition of K', we condition on more favorable information, namely, the fact that no credit was provided at τ implies that $s_\tau \in \{s_L, s_U\}$ as opposed to $s_\tau = s_L$ in the definition of K^*. It therefore must be the case that $K' \geq K^*$.[42] Denote the expected social welfare under σ by P^*. Notice that P^* can be written as,

$$\begin{aligned} P^* \;=\; & [\Pr(s_U \mid \lambda_L) + \Pr(s_H \mid \lambda_L)] \Pr(\lambda_L \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_L] \\ & + [\Pr(s_U \mid \lambda_H) + \Pr(s_H \mid \lambda_H)] \Pr(\lambda_H \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_H] \\ & + \Pr(s_L \mid \lambda_L) \left[1 - [1 - \Pr(s_H \mid \lambda_L)]^{K^*}\right] \Pr(\lambda_L \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_L] \\ & + \Pr(s_L \mid \lambda_H) \left[1 - [1 - \Pr(s_H \mid \lambda_H)]^{K^*}\right] \Pr(\lambda_H \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_H]. \end{aligned}$$

Similarly, denote the expected social welfare under σ' by P'. P' can be written as,

$$\begin{aligned} P' \;=\; & \\ & \Pr(s_H \mid \lambda_L) \Pr(\lambda_L \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_L] \\ & + \Pr(s_H \mid \lambda_H) \Pr(\lambda_H \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_H] \\ & + [\Pr(s_L \mid \lambda_L) + \Pr(s_U \mid \lambda_L)] \left[1 - [1 - \Pr(s_H \mid \lambda_L)]^{K'}\right] \Pr(\lambda_L \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_L] \\ & + [\Pr(s_L \mid \lambda_H) + \Pr(s_U \mid \lambda_H)] \left[1 - [1 - \Pr(s_H \mid \lambda_H)]^{K'}\right] \Pr(\lambda_H \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_H] \\ \geq\; & \\ & \Pr(s_H \mid \lambda_L) \Pr(\lambda_L \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_L] \\ & + \Pr(s_H \mid \lambda_H) \Pr(\lambda_H \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_H] \\ & + [\Pr(s_L \mid \lambda_L) + \Pr(s_U \mid \lambda_L)] \left[1 - [1 - \Pr(s_H \mid \lambda_L)]^{K^*}\right] \Pr(\lambda_L \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_L] \\ & + [\Pr(s_L \mid \lambda_H) + \Pr(s_U \mid \lambda_H)] \left[1 - [1 - \Pr(s_H \mid \lambda_H)]^{K^*}\right] \Pr(\lambda_H \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_H]. \end{aligned}$$

because $K' \geq K^*$ implies that when we substitute K^* for K' in P' either we subtract some positive term(s) from P' (when $K' > K^*$) or it makes no difference (when $K' = K^*$).[43] It follows that,

$$\begin{aligned} & P^* - P' \\ \leq\; & \Pr(s_U \mid \lambda_L) [1 - \Pr(s_H \mid \lambda_L)]^{K^*} \Pr(\lambda_L \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_L] \\ & + \Pr(s_U \mid \lambda_H) [1 - \Pr(s_H \mid \lambda_H)]^{K^*} \Pr(\lambda_H \mid h_{\tau-1}) E[W(C,\omega) \mid \lambda_H] \\ =\; & \Pr(s_U \mid \lambda_L) E[W(C,\omega) \mid \sigma, h_{\tau-1}, s_\tau = s_L, s_{\tau+k} \in \{s_L, s_U\}\ \forall k \in \{1, ..., K^*\}, s_{\tau+K^*+1} = s_H] \\ \leq\; & 0. \end{aligned}$$

because, by definition of K^*, the penultimate expression is non-positive. Furthermore, if $K' > K^*$, the first inequality above is strict; and if $K' = K^*$, the second inequality must be

[42] This can be verified algebraically.

[43] In order to see this, recall that P' is a series of $K' + 1$ positive terms, where the k'th term is the probability that bank $\tau + k$ invests times the conditional expected welfare from this investment.

strict because

$$\begin{aligned} & E\left[W\left(C,\omega\right) \mid \sigma, h_{\tau-1}, s_\tau = s_L, s_{\tau+k} \in \left\{s_L, s_U\right\} \ \forall k \in \left\{1, ..., K^*\right\}, s_{\tau+K^*+1} = s_H\right] \\ < \ & E\left[W\left(C,\omega\right) \mid \sigma', h_{\tau-1}, s_{\tau+k} \in \left\{s_L, s_U\right\} \ \forall k \in \left\{0, ..., K'\right\}, s_{\tau+K'+1} = s_H\right], \end{aligned}$$

which by assumption is non-positive.

The last sentence of in the statement of the Proposition follows from the fact that when strategies are monotone non-decreasing, there is a finite integer K such that

$$E\left[W\left(C,\omega\right) \mid \sigma', h_\tau, s_{\tau+k} \in \left\{s_L, s_U\right\} \text{ for all } k \in \left\{1, ..., K-1\right\}, s_{\tau+K} = s_H\right] \leq 0.$$

■

Proof of Proposition 2. Suppose that σ is a profile of efficient monotone non-decreasing strategies. Because of the previous three lemmas it is sufficient to show that it is impossible that σ prescribes investment upon observation of an uninformative signal. Moreover, we need to consider only the case that is not covered by Proposition 3. Suppose then that after some history h_{t-1} bank t is the last to provide credit upon observation of an uninformative signal, that no credits have been provided before t, and that the history h_{t-1} does not imply that at most C credits will be provided. Such a last bank exists because, by monotonicity, failure to invest for a sufficiently long number of periods indicates that the probability of the state $\lambda = \lambda_H$ is so low that it discourages investment altogether.

For any $t \in \{1, 2, ...\}$, let $V_t(\gamma_t, p_t)$ denote the expected social welfare from continuing to follow the efficient monotone non-decreasing strategy profile, conditional on the number of credits provided by time t, denoted γ_t, and the probability of the good state $\lambda = \lambda_H$, denoted p_t. Consider an alternative strategy profile, denoted σ', that is identical to σ everywhere except that under σ'_t investment is made if and only if s_H is observed and under σ'_{t+1} investment is made if and only if either s_H or s_U is observed. The idea of the proof is first to show that σ and σ' generate the exact same expected social welfare, and then to argue that σ', and thus σ, cannot be efficient because, by Proposition 3, it is strictly suboptimal to provide credit upon observation of an uninformative signal when C credits have already been provided.

The following Table 2 describes the expected social welfare under σ as a function of all the possible signal realizations in t and $t+1$:[44]

[44] For the first two lines of Table 2 note that because (by assumption) the history h_{t-1} does not imply that at most C credits will be provided, the strategy σ_{t+1} must prescribe bank $t+1$ to invest upon observation of a high signal, if bank t has invested. For the line corresponding to (s_L, s_H) note that the strategy σ_{t+1} must prescribe bank $t+1$ to invest upon observation of a high signal, if bank t has not invested, because it prescribes bank t to invest upon observation of the non-informative signal s_U, and the information $I = \{s_t = s_L, s_{t+1} = s_H\}$ is equivalent to the information $s_t = s_U$.

(s_t, s_{t+1})	expected social welfare conditional on σ and h_{t+1}
(s_H, s_H)	$E\left[W(2C,\omega) \mid h_{t-1}, s_t \in \{s_U, s_H\}, s_{t+1} = s_H\right]$
(s_U, s_H)	$E\left[W(2C,\omega) \mid h_{t-1}, s_t \in \{s_U, s_H\}, s_{t+1} = s_H\right]$
(s_H, s_U)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_U, s_H\}, s_{t+1} \in \{s_L, s_U\})\right]$
(s_L, s_H)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t = s_L, s_{t+1} = s_H)\right]$
(s_H, s_L)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_U, s_H\}, s_{t+1} \in \{s_L, s_U\})\right]$
(s_U, s_U)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_U, s_H\}, s_{t+1} \in \{s_L, s_U\})\right]$
(s_L, s_U)	$V\left[0, \Pr(\lambda_H \mid h_{t-1}, s_t = s_L, s_{t+1} \in \{s_L, s_U\})\right]$
(s_U, s_L)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_U, s_H\}, s_{t+1} \in \{s_L, s_U\})\right]$
(s_L, s_L)	$V\left[0, \Pr(\lambda_H \mid h_{t-1}, s_t = s_L, s_{t+1} \in \{s_L, s_U\})\right]$

Table 2

Table 3 describes the expected social welfare under σ' as a function of all the possible signal realizations in t and $t+1$:

(s_t, s_{t+1})	expected social welfare conditional on σ' and h_{t+1}
(s_H, s_H)	$E\left[W(2C,\omega) \mid h_{t-1}, s_t = s_H, s_{t+1} \in \{s_U, s_H\}\right]$
(s_U, s_H)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_L, s_U\}, s_{t+1} \in \{s_U, s_H\})\right]$
(s_H, s_U)	$E\left[W(2C,\omega) \mid h_{t-1}, s_t = s_H, s_{t+1} \in \{s_U, s_H\}\right]$
(s_L, s_H)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_L, s_U\}, s_{t+1} \in \{s_U, s_H\})\right]$
(s_H, s_L)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t = s_H, s_{t+1} = s_L)\right]$
(s_U, s_U)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_L, s_U\}, s_{t+1} \in \{s_U, s_H\})\right]$
(s_L, s_U)	$V\left[C, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_L, s_U\}, s_{t+1} \in \{s_U, s_H\})\right]$
(s_U, s_L)	$V\left[0, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_L, s_U\}, s_{t+1} = s_L)\right]$
(s_L, s_L)	$V\left[0, \Pr(\lambda_H \mid h_{t-1}, s_t \in \{s_L, s_U\}, s_{t+1} = s_L)\right]$

Table 3

Tables 2 and 3 demonstrate that the expected social welfare under σ and σ' is identical. This follows from the fact that (a) the probabilities of observing any sequence of signals is identical in both tables, and (b) the order in which the signals s_t and s_{t+1} are observed is irrelevant as of time $t+2$ and onwards. Thus, the rows that correspond to signals $(s_t, s_{t+1}) = (s_i, s_j)$, $s_i, s_j \in \{s_L, s_U, s_H\}$, in Table 2 yield the same value function as the rows that correspond to $(s_t, s_{t+1}) = (s_j, s_i)$ in Table 3, respectively. ■

Proof of Proposition 4. The proof is straightforward. Banks should be taxed so that only those that have observed the highest possible signal will want to provide credit. The tax/subsidy can be further refined so that the banks' objective function coincides with social welfare. ■

Appendix B: Numerical Examples

This appendix provides the details of the numerical calculations used for the seven numerical examples presented in the paper. In order to make it self-contained, the examples are replicated before the calculations are given. Each of the first seven sections of this appendix contains one example. The last section contains a table with conditional probabilities and expected values that are relevant for the first six of the seven examples.

A. Example 1: Herding

A.1. The Stochastic Environment

$\Pr(\lambda_L) = \Pr(\lambda_H) = 0.5.$
$\Pr(\theta_1) = 0.01$, $\Pr(\theta_2) = 0.04$, $\Pr(\theta_3) = 0.95.$

A.2. The Information Structure

$\Pr(s_U) = 0.25$, $\Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = 0.5$, $\Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = 0.25.$

A.3. The Payoffs

$y = -500$, $x_L = -420$, $x_H = 630.$

A.4. Herding

There is a perfect Bayesian equilibrium that has the following properties. Bank 1 invests if and only if $s_1 \in \{s_U, s_H\}$. Bank 2 invests if and only if either bank 1 has invested (in which case bank 2 invests regardless of its signal s_2), or bank 1 has not invested but $s_2 = s_H$. Bank 3 invests if and only if bank 1 has not invested, bank 2 has invested, and $s_3 \in \{s_U, s_H\}$. Finally, bank 4 invests if and only if banks 1 and 3 have not invested, bank 2 has invested, and $s_4 = s_H$. All other banks never invest. The probability that at the end of the first stage of the game exactly one bank has invested is only $1/32 = 0.03125$, whereas the probability that two banks have invested is $23/32 = 0.71875$ and the probability that no bank ever invests is $1/4 = 0.25$. In the latter case an "informational cascade," that occurs after bank 1 and bank 2 have both declined to invest, makes it impossible to infer the signal of bank 3 (and of any bank that would move after bank 3), and all banks herd on declining to invest. A similar informational cascade, starting with bank 5, occurs if the signal realizations are such that only one bank invests.

A.5. Details

The following calculations (which make use of Table 6 in Section H of this Appendix) prove the example:

$$
\begin{aligned}
& E\left[\pi(1,1,\omega) \mid s_1 = s_L\right] = -5 - 0.099 \times 70 < 0, \\
& E\left[\pi(1,1,\omega) \mid s_1 = s_U\right] > E\left[\pi(1,2,\omega) \mid s_1 = s_U\right] \\
& \quad = -25 + 0.95 \times 105 = 74.75 > 0, \\
& E\left[\pi(1,2,\omega) \mid a_1 = 1, s_2 = s_L\right] = E\left[\pi(1,2,\omega) \mid s_1 \in \{s_U, s_H\}, s_2 = s_L\right] \\
& \quad = -25 + 0.95 \times 30 = 3.5 > 0, \\
& E\left[\pi(1,1,\omega) \mid a_1 = 0, s_2 = s_U\right] = E\left[\pi(1,1,\omega) \mid s_1 = s_L, s_2 = s_U\right] \\
& \quad = E\left[\pi(1,1,\omega) \mid s_1 = s_L\right] < 0, \\
& E\left[\pi(1,1,\omega) \mid a_1 = 0, s_2 = s_H\right] = E\left[\pi(1,1,\omega) \mid s_1 = s_L, s_2 = s_H\right] \\
& \quad = E\left[\pi(1,1,\omega) \mid s_1 = s_U\right] > 0, \\
& E\left[\pi(1,1,\omega) \mid a_1 = 0, a_2 = 0, s_3 = s_H\right] \\
& \quad = E\left[\pi(1,1,\omega) \mid s_1 = s_L, s_2 \in \{s_L, s_U\}, s_3 = s_H\right] \\
& \quad = E\left[\pi(1,1,\omega) \mid s_2 \in \{s_L, s_U\}\right] = -5 < 0, \\
& E\left[\pi(1,2,\omega) \mid a_1 = 0, a_2 = 1, s_3 = s_U\right] = E\left[\pi(1,2,\omega) \mid s_1 = s_L, s_2 = s_H, s_3 = s_U\right] \\
& \quad = E\left[\pi(1,2,\omega) \mid s_3 = s_U\right] = E\left[\pi(1,2,\omega) \mid s_1 = s_U\right] > 0, \\
& E\left[\pi(1,2,\omega) \mid a_1 = 0, a_2 = 1, s_3 = s_L\right] = E\left[\pi(1,2,\omega) \mid s_1 = s_L, s_2 = s_H, s_3 = s_L\right] \\
& \quad = E\left[\pi(1,2,\omega) \mid s_3 = s_L\right] < 0, \\
& E\left[\pi(1,2,\omega) \mid a_1 = 0, a_2 = 1, a_3 = 0, s_4 = s_H\right] \\
& \quad = E\left[\pi(1,2,\omega) \mid s_1 = s_L, s_2 = s_H, s_3 = s_L, s_4 = s_H\right] \\
& \quad = E\left[\pi(1,2,\omega) \mid s_1 = s_U\right] > 0, \\
& E\left[\pi(1,2,\omega) \mid a_1 = 0, a_2 = 1, a_3 = 0, s_4 = s_U\right] \\
& \quad = E\left[\pi(1,2,\omega) \mid s_1 = s_L, s_2 = s_H, s_3 = s_L, s_4 = s_U\right] \\
& \quad = E\left[\pi(1,2,\omega) \mid s_1 = s_L\right] < 0, \\
& E\left[\pi(1,2,\omega) \mid a_1 = 0, a_2 = 1, a_3 = 0, a_4 = 0, s_5 = s_H\right] \\
& \quad = E\left[\pi(1,2,\omega) \mid s_1 = s_L, s_2 = s_H, s_3 = s_L, s_4 \in \{s_L, s_U\}, s_5 = s_H\right] \\
& \quad = E\left[\pi(1,2,\omega) \mid s_4 \in \{s_L, s_U\}\right] < E\left[\pi(1,1,\omega) \mid s_2 \in \{s_L, s_U\}\right] < 0, \\
& E_{(\gamma,\omega)}\left[\pi(1,\gamma,\omega) \mid a_1 = 0, s_2 = s_H\right] = E\left(_{\gamma,\omega}\right)\left[\pi(1,\gamma,\omega) \mid s_1 = s_L, s_2 = s_H\right] \\
& \quad = \Pr\left(s_3 \in \{s_U, s_H\} \mid s_1 = s_L, s_2 = s_H\right) \times \\
& \qquad\qquad E\left[\pi(1,2,\omega) \mid s_1 = s_L, s_2 = s_H, s_3 \in \{s_U, s_H\}\right] + \\
& \qquad \Pr\left(s_3 = s_L \mid s_1 = s_L, s_2 = s_H\right) \Pr\left(s_4 \in \{s_L, s_U\} \mid s_1 = s_L, s_2 = s_H, s_3 = s_L\right) \times \\
& \qquad\qquad E\left[\pi(1,1,\omega) \mid s_1 = s_L, s_2 = s_H, s_3 = s_L, s_4 \in \{s_L, s_U\}\right] + \\
& \qquad \Pr\left(s_3 = s_L \mid s_1 = s_L, s_2 = s_H\right) \Pr\left(s_4 = s_H \mid s_1 = s_L, s_2 = s_H, s_3 = s_L\right) \times \\
& \qquad\qquad E\left[\pi(1,2,\omega) \mid s_1 = s_L, s_2 = s_H, s_3 = s_L, s_4 = s_H\right] \\
& \quad = \tfrac{5}{8} 174.5 + \tfrac{3}{8}\tfrac{2}{3}(-157.5) + \tfrac{3}{8}\tfrac{1}{3} 74.75 = \tfrac{632.25}{8} > 0.
\end{aligned}
$$

B. Example 2: Non-Uniqueness of the Perfect Bayesian Equilibrium

B.1. The Stochastic Environment

$\Pr(\lambda_L) = \Pr(\lambda_H) = 0.5.$
$\Pr(\theta_1) = .05,\ \Pr(\theta_2) = 0.25,\ \Pr(\theta_3) = 0.7.$

B.2. The Information Structure

$\Pr(s_U) = 0.25,\ \Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = 0.5,\ \Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = 0.25.$

B.3. The Payoffs

$y = -500,\ x_L = -420,\ x_H = 630.$

B.4. Non-Uniqueness

There is a perfect Bayesian equilibrium where bank 1 invests if and only if $s_1 \in \{s_U, s_H\}$, and if bank 1 has invested (i.e., after a history $h_1 = 1$) bank 2 invests if and only if $s_2 = s_H$.

There is also a perfect Bayesian equilibrium where bank 1 invests if and only if $s_1 = s_H$, and if bank 1 has invested (i.e., after a history $h_1 = 1$) bank 2 invests if and only if. $s_2 \in \{s_U, s_H\}$.

B.5. Details

The following table (which makes use of Table 6 in Section H of this Appendix) gives for $\gamma = C$ or $\gamma = 2C$, respectively, the expected payoffs conditional on a selection of signal events.

I	$\gamma = C$	$\gamma = 2C$
s_U	74.75	−76.5
s_H		46
s_L	−91.5	
$s_H \wedge s_H$		144
$\{s_L, s_U\}$	−25	
$s_H \wedge \{s_L, s_U\}$	146	
$\{s_U, s_H\}$		−3
$s_H \wedge \{s_U, s_H\}$		107.25

Table 4

a) Equilibrium I: Bank 1 invests if and only if $s_1 \in \{s_U, s_H\}$; and if $a_1 = 1$, bank 2 invests if and only if $s_2 = s_H$.

The following calculations prove that these strategies are, in fact, optimal:

$E[\pi(1,2,\omega) \mid a_1 = 1, s_2 = s_H] = E[\pi(1,2,\omega) \mid s_1 \in \{s_U, s_H\}, s_2 = s_H]$
$= 107,25 > 0,$

$E[\pi(1,2,\omega) \mid a_1 = 1, s_2 = s_U] = E[\pi(1,2,\omega) \mid s_1 \in \{s_U, s_H\}] = -3 < 0,$
$E_{(\gamma,\omega)}[\pi(1,\gamma,\omega) \mid s_1 = s_U] =$
$\Pr(s_2 = s_H \mid s_1 = s_U) \times 46 + \Pr(s_2 \in \{s_L, s_U\} \mid s_1 = s_U) \times (-25) = \frac{3}{8} \times 46 - \frac{5}{8} \times 25$
$= 1.625 > 0,$
$E[\pi(1,1,\omega) \mid s_1 = s_L] = -91.5 < 0.$

b) Equilibrium II: Bank 1 invests if and only if $s_1 = s_H$; and if $a_1 = 1$, bank 2 invests if and only if $s_2 \in \{s_U, s_H\}$.

The following calculations prove that these strategies are, in fact, optimal:
$E[\pi(1,2,\omega) \mid a_1 = 1, s_2 = s_U] = E[\pi(1,2,\omega) \mid s_1 = s_H] = 46 > 0,$
$E[\pi(1,2,\omega) \mid a_1 = 1, s_2 = s_L] = E[\pi(1,2,\omega) \mid s_1 = s_H, s_2 = s_L]$
$= E[\pi(1,2,\omega) \mid s = s_U] = -76.5 < 0,$
$E_{(\gamma,\omega)}[\pi(1,\gamma,\omega) \mid s_1 = s_H] =$
$\Pr(s_2 \in \{s_U, s_H\} \mid s_1 = s_H) \times 107.25 + \Pr(s_2 = s_L \mid s_1 = s_H) \times 74.75 > 0,$
$E_{(\gamma,\omega)}[\pi(1,\gamma,\omega) \mid s_1 = s_U]$
$= \Pr(s_2 \in \{s_U, s_H\} \mid s_1 = s_U) \times (-3) + \Pr(s_2 = s_L \mid s_1 = s_U) \times (-91.5) < 0.$

C. Example 3: First Mover's Curse

C.1. The Stochastic Environment

$\Pr(\lambda_L) = \Pr(\lambda_H) = 0.5.$
$\Pr(\theta_1) = 0.25,\ \Pr(\theta_2) = 0.15,\ \Pr(\theta_3) = 0.6.$

C.2. The Information Structure

$\Pr(s_U) = 0.25,\ \Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = 0.5,\ \Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = 0.25.$

C.3. The Payoffs

$y = -600,\ x_L = -420,\ x_H = 630.$

C.4. The Equilibrium

There is a unique perfect Bayesian equilibrium. In this equilibrium no bank ever invests, regardless of its signal, in spite of the fact that $E\left[\pi\left(1,1,\omega\right) \mid s_H\right] = 60 > 0$. The reason why no bank ever invests is the first mover's curse.

C.5. Details

The following calculations (which make use of Table 6 in Section H of this Appendix) prove the example:

$E\left[\pi\left(1,1,\omega\right) \mid s_1 = s_H\right] = -150 + \frac{3}{4} \times 280 = 60 > 0,$
$E\left[\pi\left(1,2,\omega\right) \mid s_1 = s_H\right] = -240 + 0.6 \times 280 = -72 < 0,$
$E\left[\pi\left(1,2,\omega\right) \mid s_1 = s_2 = s_H\right] = -240 + 0.6 \times 420 = 12 > 0,$
$E\left[\pi\left(1,2,\omega\right) \mid s_1 = s_H, s_2 = s_U\right] = E\left[\pi\left(1,2,\omega\right) \mid s_1 = s_H\right] = -72 < 0,$
$E\left[\pi\left(1,1,\omega\right) \mid s_1 = s_U\right] = -150 + \frac{3}{4} \times 105 = -71.25 < 0,$
$E\left[\pi\left(1,1,\omega\right) \mid s_1 = s_H, s_2 \in \{s_L, s_U\}\right] = -150 + \frac{3}{4} \times 180 = -15,$
$E_{(\gamma,\omega)}\left[\pi\left(1,\gamma,\omega\right) \mid s_1 = s_H\right]$
$= \Pr\left(s_2 = s_H \mid s_1 = s_H\right) \times 12 + \Pr\left(s_2 \in \{s_L, s_U\} \mid s_1 = s_H\right) \times (-15)$
$= \frac{5}{12} \times 12 + \frac{7}{12} \times (-15) = -3.75 < 0.$

Beliefs: If $a_1 = 1$, then $s_1 = s_H$; if $a_1 = 0$, then $s_1 \in \{s_L, s_U, s_H\}$ where the respective probabilities are derived from the priors and the information structure.

Therefore, bank 1 never invests. Consequently, bank 2 is in the same situation and never invests. The same holds for all banks $t = 3, 4, ...$

D. Example 4: Investment After Unfavorable Public Information

D.1. The Stochastic Environment

$\Pr\left(\lambda_L\right) = \Pr\left(\lambda_H\right) = 0.5.$
Before the public signal: $\Pr\left(\theta_1\right) = 0.25$, $\Pr\left(\theta_2\right) = 0.15$, $\Pr\left(\theta_3\right) = 0.6$.
After the public signal: $\Pr\left(\theta_1\right) = 0.3$, $\Pr\left(\theta_2\right) = 0.2$, $\Pr\left(\theta_3\right) = 0.5$, i.e., the probability of a currency crisis increases unambiguously (first order stochastic dominance).

D.2. The Information Structure

$\Pr\left(s_U\right) = 0.25$, $\Pr\left(s_L \mid \lambda_L\right) = \Pr\left(s_H \mid \lambda_H\right) = 0.5$, $\Pr\left(s_H \mid \lambda_L\right) = \Pr\left(s_L \mid \lambda_H\right) = 0.25.$

D.3. The Payoffs

$y = -600$, $x_L = -420$, $x_H = 630.$

D.4. The Effect of the Unfavorable Public Signal on Investment

Before the public signal there is a unique perfect Bayesian equilibrium in which no bank ever invests (Example 3). After the public information there is a unique perfect Bayesian equilibrium in which bank 1 invests if and only if $s_1 = s_H$, and no other bank ever invests.

D.5. Details

The following calculations make use of Table 6 in Section H of this Appendix. After the public signal,

$$E\left[\pi\left(1,2,\omega\right) \mid s_1 = s_2 = s_H\right] = -300 + 210 = -90 < 0,$$

and thus bank 2 never invests if bank 1 has invested. Moreover,

$$E_{(\gamma,\omega)}\left[\pi\left(1,\gamma,\omega\right) \mid s_1 = s_H\right] = E\left[\pi\left(1,1,\omega\right) \mid s_1 = s_H\right] = -180 + 0.7 \times 280$$
$$= 16 > 0,$$
$$E\left[\pi\left(1,1,\omega\right) \mid s_1 = s_U\right] = -180 + 0.7 \times 105 = -106.5 < 0, \text{ and}$$
$$E\left[\pi\left(1,1,\omega\right) \mid s_1 \in \left\{s_L, s_U\right\}, s_2 = s_H\right] = -180 + 0.7 \times 180 = -54 < 0.$$

Thus, bank 1 invests if and only if $s_1 = s_H$; and no other bank ever invests.

E. Example 5: Incentives to Hide the Private Signal

E.1. The Stochastic Environment

$\Pr\left(\lambda_L\right) = \Pr\left(\lambda_H\right) = 0.5.$
$\Pr\left(\theta_1\right) = 0.1,\ \Pr\left(\theta_2\right) = 0.3,\ \Pr\left(\theta_3\right) = 0.6.$

E.2. The Information Structure

$\Pr\left(s_U\right) = 0.25,\ \Pr\left(s_L \mid \lambda_L\right) = \Pr\left(s_H \mid \lambda_H\right) = 0.5,\ \Pr\left(s_H \mid \lambda_L\right) = \Pr\left(s_L \mid \lambda_H\right) = 0.25.$

E.3. The Payoffs

$y = -600,\ x_L = -420,\ x_H = 630.$

E.4. Equilibrium

If only the actions can be observed, there is a unique perfect Bayesian equilibrium in which bank 1 invests if and only if $s_1 \in \left\{s_U, s_H\right\}$, and no other bank ever invests if bank 1 has invested. If investment reveals the signal perfectly, there is a unique perfect Bayesian equilibrium in which bank 1 invests if and only if $s_1 \in \left\{s_U, s_H\right\}$; and if bank 1 has invested after observation of $s_1 = s_H$ (thereby revealing $s_1 = s_H$), bank 2 invests if and only if $s_2 = s_H$. Conditional on $s_1 \neq s_H$, the expected payoff of bank 1 is the same in both equilibria, but conditional on $s_1 = s_H$ the expected payoff of bank 1 is 192 in the first equilibrium (where only the actions can be observed) and 64.5 in the second equilibrium (where investment reveals that bank 1 has observed the high signal). Obviously, bank 1 is better off in the first equilibrium and thus has an incentive to hide its private signal.

E.5. Details

The following calculations (which make use of Table 6 in Section H of this Appendix) prove the example:

$E[\pi(1,1,\omega) \mid s_1 = s_U] = -60 + 0.9 \times 105 = 34.5 > 0,$
$E[\pi(1,2,\omega) \mid s_1 = s_2 = s_H] = -240 + 0.6 \times 420 = 12 > 0,$
$E[\pi(1,2,\omega) \mid s_1 \in \{s_U, s_H\}, s_2 = s_H] = -240 + 0.6 \times 367.5 = -19.5 < 0,$
$E[\pi(1,2,\omega) \mid s_1 = s_H; s_2 \in \{s_L, s_U\}, s_3 = s_H] = -240 + 0.6 \times 343,64$
$= -33.82 < 0.$

Therefore, if $s_1 = s_H$ and if this can be observed by bank 2, then bank 2 invests whenever $s_2 = s_H$. On the other hand, if $s_1 = s_H$ but only the actions can be observed, then bank 2 infers only $s_1 \in \{s_U, s_H\}$ from $a_1 = 1$ and since $E[\pi(1,2,\omega) \mid s_1 \in \{s_U, s_H\}, s_2 = s_H] < 0$, it will never invest when bank 1 has invested.

Conditional on $s_1 = s_H$, if the signal $s_1 = s_H$ is not revealed the first bank's expected payoff is

$E_{(\gamma,\omega)}[\pi(1,\gamma,\omega) \mid s_1 = s_H] = E[\pi(1,1,\omega) \mid s_1 = s_H]$
$= -60 + 0.9 \times 280 = 192;$

whereas if the signal $s_1 = s_H$ is revealed, the first bank's expected payoff (again conditional on $s_1 = s_H$) is

$E_{(\gamma,\omega)}[\pi(1,\gamma,\omega) \mid s_1 = s_H]$
$= \Pr(s_2 = s_H \mid s_1 = s_H) \times 12 + \Pr(s_2 \in \{s_L, s_U\} \mid s_1 = s_H) \times (-60 + 0.9 \times 180)$
$= 64.5.$

(Since $E[\pi(1,2,\omega) \mid s_1 = s_H, s_2 = s_U] < E[\pi(1,2,\omega) \mid s_1 \in \{s_U, s_H\}, s_2 = s_H] < 0$, bank 2 does not invest after $a_1 = 1$ and $s_2 = s_U$, or after $s_2 = s_L$. Moreover, banks $t = 3, 4, ...$ never invest, since $E[\pi(1,2,\omega) \mid s_1 = s_H; s_2 \in \{s_L, s_U\}, s_3 = s_H] < 0.$)

F. Example 6: Inefficiency

F.1. The Stochastic Environment

$\Pr(\lambda_L) = 0.25$, $\Pr(\lambda_H) = 0.75$.
$\Pr(\theta_1) = 0.1$, $\Pr(\theta_2) = 0.2$, $\Pr(\theta_3) = 0.7$.

F.2. The Information Structure

$\Pr(s_U) = 0.25$, $\Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = 0.75$, $\Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = 0$.

F.3. The Payoffs

$y = -500,\ x_L = -420,\ x_H = 630.$
$Y_1 = -1000,\ Y_2 = -2000,\ X_L = -840,\ X_H = 1260$, i.e., $W(\gamma, \omega) = 2\gamma\pi(1, \gamma, \omega)$.

F.4. Efficiency and Equilibrium

The following profile of strategies is second-best optimal: (i) after any history h_{t-1} such that no bank has invested yet, bank t invests if and only if $s_t = s_H$; (ii) after any history h_{t-1} such that bank $t-1$ is the first bank that invested (i.e., $\gamma_{t-2} = 0$ and $a_{t-1} = 1$), bank t invests if and only if $s_t \in \{s_U, s_H\}$, i.e., after such a history bank t invests with probability 1. Thus, the first stage of the game ends (with probability 1) one period after the first C credits have been provided.

On the other hand, it is easy to see that the perfect Bayesian equilibrium is unique and the equilibrium strategies are as follows: (a) bank 1 invests if and only if $s_1 \in \{s_U, s_H\}$; (b) bank 2 invests if and only if bank 1 has invested (i.e., $a_1 = 1$) and $s_2 \in \{s_U, s_H\}$ (if bank 1 has not invested, i.e., if $a_1 = 0$, and thus $s_1 = s_L$, the event $s_2 = s_H$ occurs with probability 0); and (c) no other bank ever invests.

Obviously the equilibrium strategies are different from the second-best optimal strategies and credits are provided too easily in this example. In particular, bank 1 and bank 2 will both invest (i.e., $a_1 = a_2 = 1$) after the signal realization $s_1 = s_2 = s_U$, whereas according to the second-best optimal strategies neither of them should invest given their information.

F.5. Details

The following calculations make use of Table 6 in Section H of this Appendix. Since $E[W(2C, \omega) \mid \lambda_H] = -600 + 1764 = 1164 > E[W(C, \omega) \mid \lambda_H] = -100 + 1134 = 1034$, the optimal γ is $\gamma^* = 2C$ if $\lambda = \lambda_H$, and $\gamma^* = 0$ if $\lambda = \lambda_L$. Since s_L and s_H, respectively, are perfectly informative, two banks should invest as soon as the signal s_H has been revealed.

The equilibrium strategies follow from the following calculations:

$$E[\pi(1,1,\omega) \mid s_1 = s_L] = E[\pi(1,1,\omega) \mid \lambda = \lambda_H] = -428 < 0,$$
$$E[\pi(1,2,\omega) \mid s_1 = s_U] = -150 + 0.7 \times 367.5 = 107.25 > 0, \text{ and}$$
$$E_{(\gamma,\omega)}[\pi(1,\gamma,\omega) \mid s_1 = s_U] \geq$$
$$\Pr(s_2 = s_L \mid s_1 = s_U)\, E[\pi(1,1,\omega) \mid s_1 = s_L] +$$
$$\Pr(s_2 \in \{s_U, s_H\} \mid s_1 = s_U)\, E[\pi(1,2,\omega) \mid s_1 = s_2 = s_U] =$$
$$-\tfrac{3}{16} \times 428 + \tfrac{13}{16} \times 107.25 = 6.89 > 0.$$

If bank 1 does not invest, bank 2 infers $s_1 = s_L$ and observes $s_2 \in \{s_L, s_U\}$ with probability 1. Thus, with probability 1 bank 2 will not invest after $a_1 = 0$, and the same holds for every bank $t = 3, 4, ...$ On the other hand, if the first bank has invested and $s_2 \in \{s_U, s_H\}$, bank 2 will invest because

$$E[\pi(1,2,\omega) \mid s_1 \in \{s_U, s_H\}, s_2 = s_U] > E[\pi(1,2,\omega) \mid s_1 = s_U] > 0.$$

If bank 1 has invested, but bank 2 has not, each bank $t \in \{3, 4, ...\}$ infers ($s_1 = s_U$ and) $s_2 = s_L$ and therefore will not invest (with probability 1).

Beliefs: If bank 1 does not invest and bank 2 observes $s_2 = s_H$, the belief of bank 2 about s_1 is arbitrary. However these beliefs do not matter for what happens (with probability 1) along the equilibrium path.

G. Example 7: Optimal Policy May Not Be Monotone Non-Decreasing

G.1. The Stochastic Environment

$\Pr(\lambda_L) = \frac{2}{3}$, $\Pr(\lambda_H) = \frac{1}{3}$.
$\Pr(\theta_1) = 0$, $\Pr(\theta_2) = \frac{1}{12}$, $\Pr(\theta_3) = \frac{11}{12}$.

G.2. The Information Structure

$\Pr(s_U) = 0$, $\Pr(s_L \mid \lambda_L) = \Pr(s_H \mid \lambda_H) = \frac{2}{3}$, $\Pr(s_H \mid \lambda_L) = \Pr(s_L \mid \lambda_H) = \frac{1}{3}$.

G.3. The Social Payoffs

$Y_2 = -1320$, $X_L = 0$, $X_H = 180$ (since $\Pr(\theta_1) = 0$, Y_1 can be any arbitrary negative number).

G.4. Conditional Probabilities and Payoffs

Let I denote information (i.e., the set of signals that are observed or inferred) and X the random variable with realizations X_L and X_H. Thus, $E(X \mid I)$ denotes the expected social payoff conditional on information I and on the absence of a currency crisis. Table 5 below depicts a selection of signal events (i.e., information I) in the first column, the associated conditional probabilities $\Pr(\lambda_L \mid I)$ and $\Pr(\lambda_H \mid I)$ in the second and third column, respectively, and the associated conditional expected payoff $E(X \mid I)$ in the fourth column.

I	$\Pr(\lambda_L \mid I)$	$\Pr(\lambda_H \mid I)$	$E(X \mid I)$
s_H	$\frac{1}{2}$	$\frac{1}{2}$	90
$s_H \wedge s_H$	$\frac{1}{3}$	$\frac{2}{3}$	120
$s_H \wedge s_H \wedge s_H$	$\frac{1}{5}$	$\frac{4}{5}$	144

Table 5

G.5. Conclusions

These data imply that

- if only one bank invests, expected welfare conditional on any finite number of signals is positive,
- $E[W(C,\omega) \mid s_1 = s_2 = s_H] = 120$,
- $E[W(2C,\omega) \mid s_1 = s_2 = s_H] = -\frac{1320}{12} + \frac{11}{12} \times 2 \times 120 = 110$,
- $E[W(C,\omega) \mid s_1 = s_2 = s_3 = s_H] = 144$, and
- $E[W(2C,\omega) \mid s_1 = s_2 = s_3 = s_H] = -\frac{1320}{12} + \frac{11}{12} \times 2 \times 144 = 154$.

Since with monotone non-decreasing strategies at most two high signals can be detected and $E[W(C,\omega) \mid s_1 = s_2 = s_H] > E[W(2C,\omega) \mid s_1 = s_2 = s_H]$, with monotone non-decreasing strategies only one bank should invest. Moreover, because $E[W(C,\omega) \mid s_1 = s_L] > 0$, expected welfare is maximized when the first bank invests regardless of its signal. This gives an expected social payoff of $P = \frac{180}{3} = 60$.

Consider the following alternative policy (which, in fact, seems to be second-best optimal):

(i) if no bank has invested up to $t-1$, bank t invests if and only if $s_t = s_L$;

(ii) if one bank has invested before $t-1$, bank t invests if and only if $s_t = s_H$ and the expected marginal payoff from doing so is positive, i.e.,

$$E[W(2C,\omega) - W(C,\omega) \mid h_{t-1}, s_t = s_H] > 0.$$

Since $E[W(2C,\omega) \mid s_1 = s_2 = s_3 = s_H] > E[W(C,\omega) \mid s_1 = s_2 = s_3 = s_H]$, the policy implies that with positive probability two banks invest. Consequently, (a) with probability 1 at least one bank invests; and (b) with positive probability a second bank invests, in which case the marginal payoff from doing so is positive. It follows that the expected social payoff P' from this policy exceeds 60, i.e., $P' > 60 = P$.

If we replace $X_L = 0$ by $X_L = -\epsilon$, where ϵ is a small positive number, the second-best optimal strategies will still not all be monotone non-decreasing, since the loss from providing C credits can be made arbitrarily small, even for $\lambda = \lambda_L$, if ϵ is chosen sufficiently small. In particular, this loss can be made smaller than the expected gain from choosing the alternative strategy specified in the example. Similarly, the example can be modified to have a positive probability $\Pr(\theta_1) > 0$ and a negative payoff $Y_1 < 0$ such that $\Pr(\theta_1) Y_1$ is sufficiently small in absolute value. Also, the probability of the uninformative signal s_U can be positive instead of $\Pr(s_U) = 0$. All these modifications, if done carefully, would not change the basic conclusions.

H. Conditional Probabilities And Expected Payoffs Absent A Currency Crisis

Let I denote information (i.e., the set of signals that are observed or inferred) and x the random variable with realizations x_L and x_H. Thus, $E(x \mid I)$ denotes the expected payoff conditional on information I and on the absence of a currency crisis. The values of $E(x \mid I)$ that are given in Table 6 below are calculated for $x_L = -420$ and $x_H = 630$ and thus apply to Examples 1-6. Table 6 below depicts a selection of signal events (i.e., information I) in the first column, the associated conditional probabilities $\Pr(\lambda_L \mid I)$ and $\Pr(\lambda_H \mid I)$ in the second and third column, respectively, and the associated conditional expected payoff absent a currency crisis, $E(x \mid I) = \Pr(\lambda_H \mid I) \times 630 - \Pr(\lambda_L \mid I) \times 420$, in the fourth column.

I	$\Pr(\lambda_L \mid I)$	$\Pr(\lambda_L \mid I)$	$E(x \mid I)$
s_U	$\frac{1}{2}$	$\frac{1}{2}$	105
s_H	$\frac{1}{3}$	$\frac{2}{3}$	280
s_L	$\frac{2}{3}$	$\frac{1}{3}$	-70
$s_H \wedge s_H$	$\frac{1}{5}$	$\frac{4}{5}$	420
$\{s_L, s_U\}$	$\frac{3}{5}$	$\frac{2}{5}$	0
$s_L \wedge \{s_L, s_U\}$	$\frac{3}{4}$	$\frac{1}{4}$	-157.5
$s_H \wedge \{s_L, s_U\}$	$\frac{3}{7}$	$\frac{4}{7}$	180
$\{s_U, s_H\}$	$\frac{2}{5}$	$\frac{3}{5}$	210
$s_L \wedge \{s_U, s_H\}$	$\frac{4}{7}$	$\frac{3}{7}$	30
$s_H \wedge \{s_U, s_H\}$	$\frac{1}{4}$	$\frac{3}{4}$	367.50
$s_H \wedge s_H \wedge \{s_L, s_U\}$	$\frac{3}{11}$	$\frac{8}{11}$	343.64

Table 6

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