

Do Miracles Lead to Crises?: An Informational Frictions Explanation to Emerging Market Financial Crises*

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Abstract

Emerging market financial crises are abrupt and dramatic, usually occurring after a period of high capital flows and high investor confidence, for example, the Asian crisis followed the Asian miracle. This paper develops an equilibrium asset pricing model with informational frictions in which the vulnerability and crisis are *consequences* of the investor confidence built in the period preceding the crisis. The model features two sets of investors, domestic and foreign, and informational frictions are introduced as follows: foreign investors are imperfectly informed about the true state of the emerging economy (asymmetric information). Foreign investors have noisy information about the true state of productivity, which contains information relevant for returns from equity. These investors solve a signal extraction problem in order to formulate expectations of the state of productivity conditional on the noisy information, called “beliefs”. Depending on the noisiness of the signal, foreign investors’ beliefs over or underestimate the true productivity of the economy. The numerical analysis shows that, if preceded by a sequence of positive signals, a small negative noise shock can trigger a sharp downward adjustment in investors’ beliefs and asset prices. The magnitude of this downward adjustment *increases at an increasing rate* with the level of confidence obtained prior to the negative signal. Moreover, with the introduction of the informational frictions, asset prices display persistence in response to transitory shocks and the misperceptions of foreign investors have amplified effects on asset prices.

JEL Classification: *F41, D82, G15*

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1 Introduction

The emerging capital markets are vulnerable to significant shifts in investors' confidence in both upward and downward directions. More interestingly, downward shifts in confidence and financial market collapses are abrupt often taking place after a period of confidence building and boom. Calvo and Reinhart (2000) document that “sudden stops”, sharp negative reversals of capital flows, are usually preceded by a surge in capital inflows. In this paper, we present a model in which the vulnerability and crises stem from the high investor confidence in the pre-crisis period.

The key ingredient of our model is *informational frictions*, motivated with the observation that emerging economies tend to follow non-transparent policies. Lack of transparency, that manifests itself by inaccurate and misleading data, has been documented to be a characteristic of emerging economies, becoming particularly prevalent in the pre-crisis periods. IMF (2001) reports that “... A lack of transparency was a feature of the build-up to the Mexican crisis of 1994-95 and of the emerging market crises of 1997-98. In these crises, markets were kept in the dark about important developments and became first uncertain and then unnerved as a host of interrelated problems came to light. Inadequate economic data, hidden weaknesses in financial systems, and a lack of clarity about government policies and policy formulation contributed to a loss of confidence that ultimately threatened to undermine global stability ...”

The model features two types of investors, domestic and foreign. Domestic investors are consumer-investors, who maximize the expected present discounted value of their lifetime utility. Foreign investors face trading costs and maximize the expected present discounted value of profits from investing in the emerging equity market.

We model the informational frictions as follows. Domestic investors have access to “better” information about the state of the economy than their foreign counterparts.¹ Foreign investors can only partially infer the true state of productivity, which contains information about the returns in the capital market. In every period, foreign investors observe dividends, a noisy signal, and update their beliefs about the current state of productivity. The dividends consist of two parts: a persistent component, which we interpret as productivity, and a transitory component,

¹For an alternative modelling of the informational frictions, see section 6.3 where we solve the case in which both sets of investors are imperfectly informed. We find that the main results of the paper are robust to these alternative informational structures. Hence, the crucial assumption is not the heterogeneity of information, but the imperfection of information.

which is a noise term.

Foreign investors' demand for equity depends on their perceptions about the productivity of the emerging economy. When they receive a negative signal, they turn pessimistic and decrease their demand for equity. The magnitude of their response to this shock varies depending on their current beliefs. If the negative signal comes after a period of positive signals and as a result it "challenges" their beliefs, their response is abrupt and large. If the signal "confirms" the beliefs, the effects of the shock are smaller.²

Domestic households are modelled as risk averse consumer-investors. The signals are in the form of dividends, hence a low signal is the same as a low dividend income. Without any informational frictions (full information), domestic investors lower their demand in response to this negative noise (and income shock) due to the consumption smoothing motive.

Informational frictions produce an effect working in the opposite direction with the consumption smoothing motive. If the transitory shock is such that the beliefs are "challenged" and assets are considerably over or underpriced, then domestic investors would like to exploit their opportunity for capital gains using their informational advantage. In other words, if the assets are underpriced due to misperceptions of foreign investors, domestic investors know that prices will be at least partially corrected in the following period with a very high probability. Hence, they would like to increase their equity holding in the current period and decrease it in the following periods as the foreign investors start correcting their beliefs. Their incentives for capital gain are stronger when the transitory shock is such that the beliefs of foreign investors are "challenged" and the assets are significantly under or overpriced. In these states, capital gain incentives are as strong as the consumption smoothing motive and domestic investors choose not to change their equity position. However, in states when the beliefs are "confirmed", the consumption smoothing effect dominates and domestic investors decrease (increase) their demand for equity in response to a negative (positive) transitory component shock.

When foreign investors turn pessimistic (optimistic) equity prices are driven below (above) the "fundamentals price". In these periods, equity prices display swings that are not associated with changes in productivity. Introduction of informational frictions produces not only endogenous busts, but also booms in the equity market. Besides, informational frictions produce persistence in response to transitory noise shocks. Investors' beliefs in one period are carried to the next and

²We borrow this terminology from Moore and Schaller (2002).

used in the calculation of the next period's beliefs. If foreign investors turn pessimistic (optimistic) as response to a misleading signal, it takes several periods for them to correct their beliefs. This simple mechanism produces persistence of investors' confidence in the emerging economy. Finally, due to the persistence of the productivity shocks, the effects of foreign investors' misperceptions are amplified. The multiplier in this amplification process is increasing in the persistence of the productivity shocks and decreasing in the risk free interest rate.

The assumption of superiority of domestic investors information relies on the fact that it is costly for foreign investors to obtain country-specific information and to keep up with the developments in emerging economies due to idiosyncracies affecting financial markets in these countries, i.e. institutions, policies, political factors, legal structure, etc. As a result, it might be optimal for them not to "buy" this information.³ Calvo and Mendoza (2000) provide two arguments for why it can be optimal for them not to buy this information. First, if short selling positions are limited, the benefit of paying for costly information declines as the number of emerging economies in which to invest increases. Second, managers of investment funds may choose to mimic each others behavior instead of paying for costly information, if punishment for poor performance is high.

Although both financial and informational frictions have been blamed for the financial crises in the emerging markets, the research on quantifying the effects of informational frictions has been limited. The literature on financial frictions often utilize collateral constraints such as Mendoza and Smith (2004), Caballero and Krishnamurthy (2001), Paasche (2001) and others. Mendoza and Smith (2004) have been successful in amplifying the shocks that have the magnitude of a regular business cycle shock and producing collapses larger than the regular business cycles by introducing an "occasionally binding" margin constraint. However, the margin constraint becomes binding after a negative productivity shock. Our model is able to produce busts and booms without referring to productivity shocks. It is sufficient for the foreign investors to observe a noisy signal and turn pessimistic/optimistic about the economy. In addition, these constraints only produce collapses, not booms, i.e. they work only in one direction. Our model works in both directions which is consistent with the emerging market empirical regularities.

In the international finance literature, shifts in investor confidence have usually been analyzed

³We do not however, explicitly model the foreign investors' decisions to be informed or to remain uninformed.

within the context of currency crises, often using models that produce multiple equilibria.⁴ In models with multiple equilibria, switches between a “good” equilibrium and a “bad” one are interpreted as changes in investor confidence that are not necessarily induced by changes in economic fundamentals.⁵ In contrast, we consider a single equilibrium model that can endogenously produce shifts in foreign investors’ confidence and switches between “good” states and “bad” ones. Modelling shifts in investors confidence without referring to multiple equilibria offers several advantages. For example, in our model we have definite answers to when these shifts occur and how long it takes for the market to recover after a bust, and finally we can analyze the dynamics during a transition from the bad state to the good one and vice versa. Moreover, in the multiple equilibria models the busts and booms are “self-fulfilling”. This feature exists in our model as well. In our model, due to misleading signals asset prices can bust or boom due to shifts in foreign investors’ expectations as well as due to changes in the fundamentals of the economy.

In addition to the literature on currency crises, recently, Gourinchas and Tornell (2003) and Andersen and Beier (2005) utilize imperfect information and learning about persistent and transitory shocks in order to account for empirical regularities regarding exchange rate dynamics.

This paper’s aim to model informational asymmetries to explain the crashes of asset prices in emerging markets is in line with Calvo’s analysis of the Russian crisis based on an informational-frictions framework. When both informed (specialists) and uninformed investors operate in the capital market, the uninformed face a signal extraction problem. In Calvo (1999), uninformed investors are able to observe actions of the informed. However, if they observe the informed staying out of the market, they cannot tell if the reason behind this action is an information about the true returns of the capital market or margin calls on highly-leveraged informed investors. The major difference between Calvo’s work and this paper is the way we distinguish the investors in terms of their information. Instead of the specialist vs. non-specialist distinction, we deal with foreign and domestic investors.

The fact that domestic portfolio investors have an informational advantage over foreign portfolio investors is also utilized by Razin, Sadka and Yuen (1999). The authors distinguish between foreign portfolio investment (FPI) and foreign direct investment (FDI) . FDI investors not only

⁴Morris and Shin (1998) demonstrate that unique equilibrium can be obtained when the speculators have noisy information about the fundamentals.

⁵Masson (1999) surveys the literature on currency crises and multiple equilibria.

have an informational advantage over foreign portfolio investors but also they are more informed than domestic savers. They consider an economy with a large number of ex-ante identical domestic firms. Each of these firms' productivity factor is random and independent across all firms. In their framework, there is no aggregate uncertainty since the productivity factor is idiosyncratic. In contrast, this paper emphasizes aggregate uncertainty in an asymmetric information framework thus, differentiating from that of Razin, Sadka and Yuen (1999). Informational asymmetry addressed in this paper stems from the foreign portfolio investors' lack of information regarding the productivity of the whole economy, not regarding the productivity of individual firms operating in the country.

Modelling dividends as noisy signals has been widely used in the literature. An incomplete list of authors utilizing this modelling strategy is: Wang (1994), who analyzes trading volume in stock markets, Albuquerque, Bauer and Schneider (2004), investigating the effects of investor sophistication on international equity flows, Nieuwerburgh and Veldkamp (2004), explaining U.S. business cycle asymmetries in an RBC framework with asymmetric learning and Moore and Schaller (2002) emphasizing the time varying response of investment to interest rate shocks.

Empirical evidence about informational asymmetries between domestic and foreign investors is mixed. Choe, Kho and Stulz (2000), Hau (2001), Dvorak (2001) and Chan, Menkveld and Yang (2003) and Chakravarty, Sarkar and Wu (1998) find that domestic investors have more valuable information compared to foreign counterparts using data from Korea, Germany, Indonesia and China. On the other hand, Seasholes (2000), Grinblatt and Kelahaiju (2000) Wang and Stulz (1997) and Chui and Kwok (1998) use data for Taiwan, Finland, Japan and China and find that foreigners have more valuable information since they have the expertise that the domestic investors lack.

Empirical evidence with low frequency data is provided by Albuquerque, Bauer and Schneider (2004) who build a structural model in order to match dividends and equity flows (from the U.S. to the other G7 countries) data and estimate the degree of informational heterogeneity within and across the countries. One of their main findings is that within country heterogeneity is more pronounced compared to the cross country heterogeneity for their sample. However, for the case of Italy, the cross country heterogeneity is found to be almost as large as the within country. They also find that an average U.S. investor is less informed than an average local investor for all 6 countries. This informational difference is slight for Canada but much larger for Italy. Although

this study focuses on developed markets, it provides important results for our purposes. Given that an average U.S. investor is less informed than an average local Canadian investor, we feel safe to assume that a representative foreign investor is less informed than a representative domestic investor in an emerging economy.

A study that provides empirical evidence on the informational asymmetry between foreign and domestic investors focusing on emerging markets is Frankel and Schmukler (1996). They find that the Mexican stock market prices Granger cause the country fund prices that are usually traded by foreign investors. They analyze the period before the Mexican crisis and show that domestic investors were the first to pull out of the equity market and interpret this finding as an evidence for domestic investors being better informed than their foreign counterparts.

Despite the mixed empirical evidence, in the first specification this paper assumes that foreign investors are less informed. However, we claim that the results presented are robust to this assumption. If there exists a group of less informed investors (whether these are domestic or foreign), equity prices will be sensitive to the noisy signals received by this group. Hence, prices will bust (boom) in periods when the noise has low (high) realizations. In order to analyze whether the heterogeneity of information plays a critical role in the model, we present a scenario where both sets of investors are imperfectly informed solving the same signal extraction problem. Like their foreign counterparts, domestic investors over or under-estimate the true productivity depending on the noisiness of the signals. We find that the results that we present in this paper survive under this alternative specification of the information structure. The major difference of this alternative set-up is equity investment becomes riskier for domestic investors due to the additional uncertainty even though the underlying process generating the dividends is the same as the asymmetric information set-up. Therefore, on average, domestic investors hold less equity. However, since the domestic investors also fall into the same misperceptions, the effects of the noisy signals on the economy are even stronger than the asymmetric information set-up.

The rest of the paper is organized as follows: Section 2 describes the structure of the model (i.e. domestic and foreign investors' problems, dividends, informational structure); Section 3 analyzes the model; Section 4 explains the computational strategies used to solve the model numerically; Section 5 reviews the calibration exercise; Section 6 shows and explains the simulation results; Section 7 investigates the symmetry of the cycles and further analyzes a case with miracles causing crises and Section 8 concludes.

2 Model

We consider a framework with two different classes of agents, foreign and domestic investors, which are identical within each class. They operate simultaneously in the equity market of the emerging economy. The fraction of foreign investors is ω and that of domestic investors is $1 - \omega$. The domestic households make consumption and equity holding decisions conditional on the true value of the productivity in order to maximize their expected present discounted value of utility. Foreign investors, however, choose their equity positions in order to maximize the expected present discounted value of profits conditional on their “belief” productivity. They do not observe the true realization of the stochastic productivity shock that contains information relevant for forecasting the returns from equity. However, they observe dividends which is a noisy signal about the true value of productivity. They form their beliefs as a solution to the signal extraction problem they face. In addition, they face trading costs associated with operating in the equity market.

2.1 Domestic Households’ Problem

Each period, for given equity prices q_t , the domestic households choose consumption c_t and equity holdings α_{t+1} in order to maximize their expected life-time utility of consumption conditional on the information available to them:

$$U = E_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_t) | I_0^i \right] \quad (1)$$

s.t.

$$c_t + \alpha_{t+1} q_t = \alpha_t (q_t + d_t) \quad (2)$$

where $u(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}$, the parameter σ is the coefficient of relative risk aversion, I_t^i is the information set of domestic investors as of time t and is defined as:

$$I_t^i = \{d_t, d_{t-1}, \dots, z_t, z_{t-1}, \dots\} \quad (3)$$

At the beginning of each period, productivity shocks are realized and dividends are determined. Households make their decisions after observing the dividends as well as the true value of productivity. The optimality conditions characterizing the household’s decisions are:

$$\beta^t u'(c_t) - \lambda_t = 0 \quad (4)$$

$$-\lambda_t q_t + E_t[\lambda_{t+1}(d_{t+1} + q_{t+1})] = 0 \quad (5)$$

where λ_t denotes the Lagrange multiplier associated with the budget constraint. Equations (4) and (5) equate the expected marginal cost and benefits of consumption and equity investment respectively.⁶ Combining these two equations gives the following Euler equation:

$$q_t u'(c_t) = \beta E_t [(q_{t+1} + d_{t+1})u'(c_{t+1})|I_t^i] \quad (6)$$

2.2 Dividends

Dividends are determined exogenously as follows:

$$d_t = z_t + \eta_t \quad (7)$$

There are two types of uncertainty associated with dividends: persistent aggregate productivity shocks z and noise in the form of transitory additive Normal i.i.d. shocks η with mean 0 and variance σ_η^2 ; $\eta \sim N(0, \sigma_\eta^2)$. Aggregate productivity shocks z , follow a Markov process with 2 states and transition probability matrix π . We denote the values z can take as $z \in \{z^L, z^H\}$.

2.3 Information Structure

We assume foreign investors know the true distribution governing the productivity shocks z , the noise η and they observe the dividends d at the beginning of each period. However, they do not observe the current or past values of the productivity shock z and the noise η .⁷ Foreign investors use the information revealed by the value of the dividends in order to infer the realization of productivity shock in the current period⁸:

$$\tilde{z}_t = E[z_t | I_t^u] \quad (8)$$

where I_t^u includes the history of the dividends observed by the foreign investors:

$$I_t^u = \{d_t, d_{t-1}, \dots\} \quad (9)$$

⁶We discuss the role of the expectation operator and the information structure in Section 2.3.

⁷One can think that they observe the productivity with such a long lag that the information is not useful for predicting the current value any more.

⁸One can model publicly observed signals revealing information rather than dividends. However, in such a set-up both the dividends and the public signals would reveal information since dividends are usually thought to be a function of the fundamentals of the economy. Our current specification is simpler and we would have similar dynamics if we had added public signals.

Since the information sets of investors can be hierarchically ranked (foreign investors' information set is a subset of domestic investors', $I^u \subset I^i$ for $\forall t$), we do not face an "infinite regress problem", i.e. agents do not forecast the forecasts of other agents avoiding an infinite dimensional belief space.

The belief \tilde{z}_t is formed by updating the previous period's belief \tilde{z}_{t-1} using Bayes' rule, similar to Nieuwerburgh and Veldkamp (2003) and Moore and Schaller (2002).

The Bayesian updating rule is:

$$Pr(z_t = z^H | \Omega_t) = \frac{f(d_t | z_t = z^H) Pr(z_t = z^H | \Omega_{t-1})}{f(d_t | z_t = z^L) Pr(z_t = z^L | \Omega_{t-1}) + f(d_t | z_t = z^H) Pr(z_t = z^H | \Omega_{t-1})} \quad (10)$$

where f is the conditional normal probability density that can be written as:

$$f(d_t | z_t = z^H) = \frac{1}{\sqrt{2\Pi}\sigma_\eta} \exp\left\{-\frac{1}{2\sigma_\eta^2}(d_t - z^H)^2\right\} \quad (11)$$

Equation (10) is used to update the probability assigned to being in the high productivity state incorporating the additional information revealed by d_t at the beginning of period t . The priors that will be used in period $t + 1$ for updating beliefs are obtained by simply adjusting for the probability of change of state from period t to $t + 1$ using the Markov transition matrix known by foreign investors. That is:

$$Pr(z_{t+1} = z^H | \Omega_t) = Pr(z_t = z^H | \Omega_t) \Pi(H, H) + Pr(z_t = z^L | \Omega_t) \Pi(L, H) \quad (12)$$

where $\Pi(i, j)$ stands for the probability of transiting from state i to state j .

Once the posteriors of the current period are calculated, the expected value of z conditional on the information available is⁹:

$$\tilde{z}_t = Pr(z_t = z^L | \Omega_t) z^L + Pr(z_t = z^H | \Omega_t) z^H \quad (13)$$

Equation (13) has 2 important implications. First, since the probabilities assigned to each state lie in the interval $[0, 1]$, beliefs are convex combinations of low and high values of productivity. As is obvious in equation (13), foreign investors take an expectation, which is a weighted average of the possible values that the productivity shock can take.¹⁰ Therefore, beliefs are always higher than the low value of productivity and lower than the high value, $z^L \leq \tilde{z} \leq z^H$. This implies

⁹Equations (10), (12) and (13) follow from Hamilton (1989).

¹⁰The weights are the probabilities assigned to being in each state.

that agents never underestimate the true productivity when the productivity is low and never overestimate when the true productivity is high. This is an unappealing feature of learning about 2 point discrete Markov processes. If we increase the points of the Markov process we would get this feature only for the lowest and the highest states.¹¹ Also, as a result of this limitation, the unconditional standard deviation of beliefs is always less than or equal to that of productivity.

Second, beliefs are sufficient to backtrack the probabilities assigned to each state. The assumption that provides this simplification is having 2 exogenous states for the productivity shocks. This simplification is crucial for the numerical analysis since probabilities assigned to each state are continuous endogenous state variables for the problem. Given the computational difficulty of handling continuous state variables, we assume 2 states for productivity shocks and carry \tilde{z} as the state variable that is sufficient for backtracking the probabilities assigned to each state of productivity.

Contrary to standard models with information where prices play a dual role; market clearing and revealing information, in this paper we abstract from the informational role of prices.¹² This is implicit in the belief updating equations where the only signals considered are the realizations of dividends. This assumption is made simply due to the difficulty of solving asymmetric information problems with learning from endogenous variables that do not have a well defined distribution which is the case with CRRA utility functions.¹³

In our set-up, if the prices had an informational role, they would be fully revealing. In models where prices have an informational role, there are several modelling strategies that make prices only partially revealing. Some of these strategies are introducing noise traders (as done in most of the papers in the literature) or a private investment opportunity available only to the informed investors where the returns from this investment is unknown to the uninformed ones. Wang (1994) builds a model with asymmetric information between two sets of investors where informed investors have a private investment opportunity. In Wang's work, equilibrium price

¹¹Despite this limitation, we choose to have 2 points for reasons discussed in the following paragraph.

¹²In section 6.3 we consider the case where both investors solve the same signal extraction problem. In that set-up we do not face the problem of prices revealing information and we find that the results do not differ significantly.

¹³To our knowledge, the only work done in solving asymmetric information problems with general utility functions is Bernardo and Judd (2000). Their method includes solution of system of non-linear equations where the number of equations in the system increase dramatically with the number of state variables and the required accuracy of the solution.

has an informational role and is a linear function¹⁴ of the return from the private investment opportunity and the persistent component of dividends (which is what the uninformed wish to know about) as well as the uninformed investors' beliefs. Learning from the equilibrium prices can be handled just like other linear and normally distributed signals.

When prices are partially revealing as in Wang (1994), prices act as a device that transmits information from the informed to the uninformed lowering the informational gap between the two. Prices not having an informational role implies that this gap will be higher compared to an identical model with prices revealing information. Our strategy to overcome this problem is to calibrate our model in a way that dividends are 'very' informative and hence the informational gap between the two investors is small. Therefore, even if we considered a set-up where prices were partially revealing, the beliefs would deviate from the true productivity almost as much as they do in the current set-up.¹⁵

An important finding of Wang (1994) for the purpose of our paper is that prices are sensitive to the misperceptions of the uninformed investors. As long as prices are not fully revealing, which is the case even in the developed equity markets, equity prices will be sensitive to the misperceptions of the uninformed investors. This is sufficient for us to claim that our results would hold in a set-up with partially revealing prices.

2.4 Foreign Investors' Problem

As in Mendoza and Smith (2004), foreign investors choose $\{\alpha_{t+1}^*\}_0^\infty$ in order to maximize the expected present discounted value of their profits conditional on their information sets:

$$E_0 \sum_{t=0}^{\infty} R^{-t} (\alpha_t^* (d_t + q_t) - \alpha_{t+1}^* q_t - q_t \frac{a}{2} (\alpha_{t+1}^* - \alpha_t^*)^2 | I_t^u) \quad (14)$$

where R is the world interest rate, $1/a$ is the price elasticity of foreign investors' demand, $q_t \frac{a}{2} (\alpha_{t+1}^* - \alpha_t^*)^2$ is the total trading cost associated with buying and selling equities in the emerging

¹⁴The model is solved analytically under very specific assumptions such as CARA utility, Kalman filters and Normally distributed returns.

¹⁵Another argument that can be brought up on this issue is that in emerging equity markets, prices can be considered to be less informative compared to the developed markets.

economies.¹⁶ The first order condition of the foreign investors' problem is:

$$q_t(1 + a(\alpha_{t+1} - \alpha_t)) = R^{-1}E[d_{t+1} + q_{t+1}(1 + a(\alpha_{t+2} - \alpha_{t+1}))|I_t^u] \quad (15)$$

The above first order condition can be simplified to:

$$\alpha_{t+1}^* - \alpha_t^* = \frac{1}{a} \left(\frac{q_t^b}{q_t} - 1 \right) \quad (16)$$

q_t^b , called the *belief price*, is the expected present discounted value of future dividends conditional on the current belief about productivity:

$$q_t^b = E[R^{-1}d_{t+1} + R^{-2}d_{t+2} + R^{-3}d_{t+3} + \dots | I_t^u] \quad (17)$$

Intuitively, foreign investors partially adjust their equity holdings depending on the gap between the market price q_t and their belief price q_t^b . How much of this gap is reflected in the equity position is determined by $1/a$.¹⁷

3 Analysis of the Model

There are two types of uncertainty faced by domestic households: the evolution of the true productivity and beliefs of foreign investors. The former is an exogenous Markov process with a distribution known to both domestic and foreign investors. The latter enters the domestic investors' problem since the introduction of imperfect information to the foreign investors' problem has implications for the domestic investors' problem as well. The beliefs of foreign investors affect equity prices and are persistent. They contain information for forecasting next period's prices. Domestic investors treat these beliefs as a state variable and form expectations about the following period's beliefs. In fact, due to their advantage in separating the persistent shocks from the noise, on average their forecasts of the future beliefs are more accurate than their foreign counterparts'. Mathematically,

$$E \left[E[\tilde{z}_{t+1}|I_t^i] - \tilde{z}_{t+1} \right] < E \left[E[\tilde{z}_{t+1}|I_t^u] - \tilde{z}_{t+1} \right] \quad (18)$$

¹⁶The trading cost associated with buying and selling equity is modelled in quadratic form as in Heaton and Lucas (1996), Aiyagari and Gertler (1999) and Mendoza and Smith (2004).

¹⁷In Mendoza and Smith (2004), the lower the trading costs the smaller the crash in equity prices however, in our set-up low trading costs (low a) imply that the changes in beliefs are reflected more to the demand functions of foreign investors inducing larger busts and booms in equity prices.

To conclude, domestic investors have an informational advantage in both of the stochastic components affecting future dividends and prices.

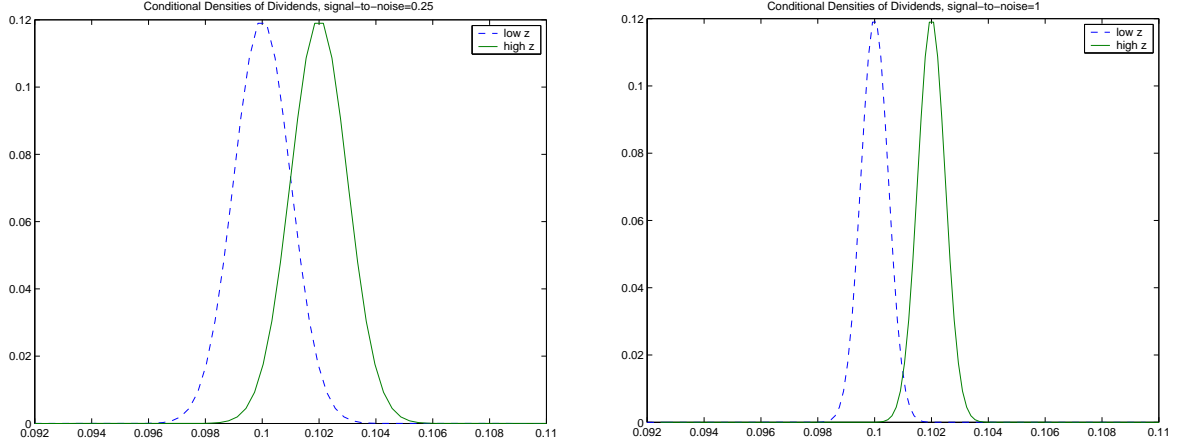


Figure 1: Density of d conditional on z for signal-to-noise ratios of 0.25 and 1.

We denote the evolution of foreign investors' beliefs as $\tilde{z}_{t+1} = \phi(\tilde{z}_t, d_{t+1})$. When domestic households make their decisions at the beginning of time t , d_{t+1} is not known whereas its distribution conditional on z_{t+1} is known. Figure (1) plots these conditional distributions for signal-to-noise ratios of 0.25 and 1, respectively. As the signal-to-noise ratio decreases, the distributions of dividends conditional on the high and low productivity overlap more and as a result dividends become less informative. In figure (1) most of the conditional density is concentrated around their means when the signal-to-noise ratio is 1. As the σ_η decreases (or as the signal-to-noise ratio increases) these two conditional densities become more separated and in limit as σ_η approaches to zero, informational asymmetry totally disappears.

In figure (2), we plot \tilde{z}_{t+1} as a function of d_{t+1} for a high (dashed line) and a low (solid line) value of \tilde{z}_t . We can make two remarks about this plot. First, the probability assigned to a particular state can be equal to one, that is, investors can be “fully sure” about the true state, if and only if as $\lim d_{t+1} \rightarrow \mp\infty$. Since the probability of an extreme realization of dividends is low¹⁸, investors will at most be “almost sure” about being in a particular state.

Second, the elasticity of \tilde{z}_{t+1} with respect to d_{t+1} varies depending on \tilde{z}_t . When the investors assign a high probability to being in the low state (\tilde{z}_t is low), a low realization of d_{t+1} “confirms” the beliefs and \tilde{z}_{t+1} changes only marginally. However, if a high d_{t+1} is observed, the beliefs of

¹⁸Recall that d_{t+1} is normally distributed, hence extreme realizations correspond to the tails of this distribution.

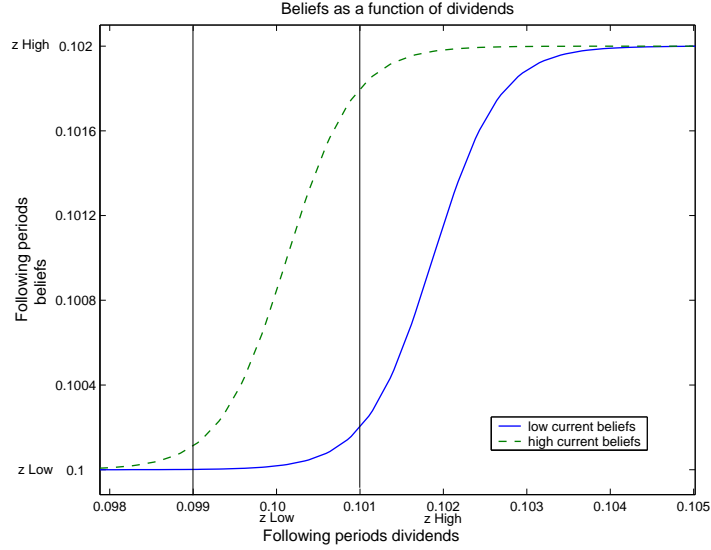


Figure 2: The following period’s beliefs \tilde{z}_{t+1} as a function of next period’s dividends d_{t+1} for a high and a low value of current beliefs \tilde{z}_t .

investors are “challenged” and there is a large adjustment in the next period’s beliefs. Most of the action takes place when the beliefs are challenged.

In order to see this clearly, consider the following scenario. Let’s assume that the true productivity is low and the signals have no noise. Foreign investors easily figure out the true productivity. The beliefs of the foreign investors are low, as shown with the solid line in figure (2). If the foreign investors observe a noisy signal in the following period, the response of the beliefs to this signal is minimal (the solid line within the band is flat). If instead, the foreign investors receive a sequence of positive signals before the negative one, even though the true productivity does not change, their confidence builds up. As investors receive these positive signals, gradually the curve shifts to the left (dashed line). When the economy ends up in such a state, the response to a small negative signal is large (the dashed line is steep within the band). Therefore, the preceding positive signals can move the economy to a vulnerable state in which a large downward adjustment eventually gets triggered.

In figure (3) we plot the numerical derivative of $\phi(\tilde{z}_t, d_{t+1})$ with respect to d_{t+1} around $d_{t+1} = z^L$ as a function of \tilde{z}_t . As can be seen from the figure, this derivative is convex. Intuitively, the response of the beliefs to a negative signal increases at an increasing rate with the degree of confidence obtained prior to the negative signal.

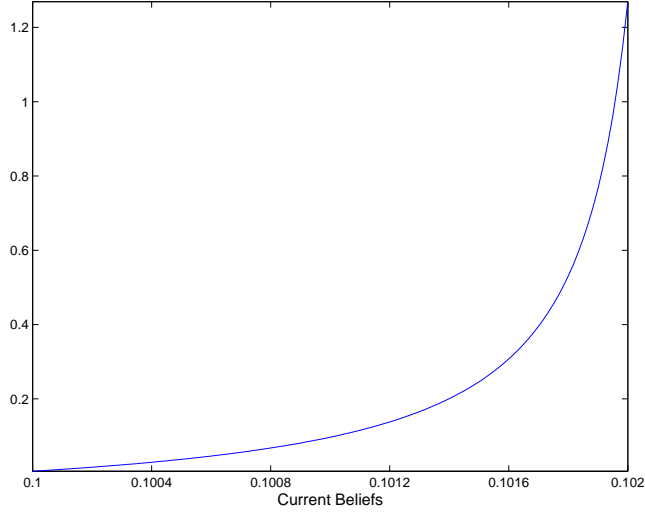


Figure 3: The derivative of following period's beliefs \tilde{z}_{t+1} with respect to dividends as a function of \tilde{z}_t .

3.1 AR(1) Specification

In order to obtain an expression linking the gap between the true productivity to beliefs to the gap between the fundamentals price and belief price, we consider the case where $z_{t+1} = \rho z_t + \epsilon_{t+1}$, $\rho \in (0, 1)$ and $\epsilon \sim N(\mu, \sigma_\epsilon^2)$ in this subsection.

In the absence of informational asymmetries and trading costs, the equilibrium price would be equal to the *fundamentals price* defined as:

$$q_t^f = E[R^{-1}d_{t+1} + R^{-2}d_{t+2} + R^{-3}d_{t+3} + \dots | I_t^i] \quad (19)$$

which is the expected present discounted value of future dividends conditional on the correct information about the current state of the economy. If there were only informational asymmetries without trading costs, equilibrium price would become the “belief” price defined in equation (17). Adding trading costs to the model lowers the demands of the foreign investors thus, forcing the equilibrium price to be lower than the belief price.

Let's rewrite equations (17) and (19) utilizing the AR(1) specification of z :

$$q_t^b = \frac{R\mu}{(R-1)(R-\rho)} + \frac{\rho\tilde{z}_t}{R-\rho} \quad , \quad q_t^f = \frac{R\mu}{(R-1)(R-\rho)} + \frac{\rho z_t}{R-\rho} \quad (20)$$

Combining these two equations gives:

$$q_t^f - q_t^b = (z_t - \tilde{z}_t) \left(\frac{\rho}{R-\rho} \right) \quad (21)$$

Any gap between the belief and true productivity gets multiplied with the term $\rho/(R - \rho)$ and is reflected to the decisions of the foreign investors.¹⁹ When $\rho/(R - \rho) > 1$ any misperception about productivity is amplified and reflected in the foreign investors' problem. This is true when $R/2 < \rho$, which is satisfied for plausible parameters, is sufficient for this amplification of $(z_t - \tilde{z}_t)$ to $(q_t^f - q_t^b)$.

The expression $\rho/(R - \rho)$ is increasing in ρ and decreasing in R . Intuitively, the higher ρ , the larger the effect of current z on the future z 's and the larger the gap between belief and fundamental price. Higher ρ implies that the misperceptions of foreign investors have a larger impact on the decision to choose their equity position. Higher interest rates however, reduce the amount of the difference between belief and true productivity transmitted to belief prices simply due to higher interest rates inducing higher discounting of future dividends.

3.2 Equilibrium

The competitive equilibrium of this economy is determined by allocations $\{\alpha_{t+1}, c_t, \alpha_{t+1}^*\}$ and prices $\{q_t\}$ such that: domestic households maximize U subject to the budget constraint taking the equity prices and the evolution of beliefs as given, foreign investors maximize the expected present discounted value of future profits conditional on their beliefs about the state of productivity taking the equity prices as given, and the goods and equity markets clear.

4 Computation

The dynamic programming representation of the domestic households problem is:

$$\begin{aligned}
 V(\alpha, \tilde{z}, \eta, z) &= \max_{\alpha', c} u(c) + \beta E[V(\alpha', \tilde{z}', \eta, z' | I^t)] \\
 &\quad \text{s.t.} \\
 c + \alpha' q &= \alpha(q + d) \\
 &\quad \text{and} \\
 \tilde{z}' &= \phi(\tilde{z}, d')
 \end{aligned} \tag{22}$$

for given prices q . In order to solve the problem numerically, we substitute for consumption using the budget constraint, substitute for \tilde{z}' using the evolution of beliefs and rewrite the problem for

¹⁹Their beliefs about productivity enter their problem only through belief price.

the high productivity state as follows:

$$V(\alpha, \tilde{z}, \eta, z^H) = \max_{\alpha'} u(\alpha(q+d) - \alpha'q) + \beta\Pi(H, H) \int V(\alpha', \phi(\tilde{z}, d'), \eta', z^H) f(d'|z^H) dd' + \beta\Pi(H, L) \int V(\alpha', \phi(\tilde{z}, d'), \eta', z^L) f(d'|z^L) dd' \quad (23)$$

Solution algorithm includes the following steps:

1. Discretize the state space. We equally space N=102 grids for α and K=40 grids for \tilde{z} in the intervals [.90, 1.00] and [0.1, 0.102] respectively.
2. Evaluate the evolution of foreign investors' beliefs $\tilde{z}_{t+1} = \phi(\tilde{z}_t, d_{t+1})$ using equations (10)-(13).²⁰
3. For a conjectured pricing function $q^{old}(\alpha, \tilde{z}, \eta, z)$, solve the dynamic programming problem using value function iterations in order to get $\alpha'(\alpha, \tilde{z}, \eta, z)$ and $c(\alpha, \tilde{z}, \eta, z)$. To evaluate the integration on the right hand side of the Bellman equation, we use Gaussian quadratures with 20 quadrature nodes.
4. Calculate foreign investors' demand function using domestic investors' equity demand function and the market clearing condition in equity market, $\omega\alpha^* + (1 - \omega)\alpha = 1$.
5. Using equation (16) calculate new prices $q^{new}(\alpha, \tilde{z}, \eta, z)$.
6. Update the conjectured prices with $(weight)q^{old}(\alpha, \tilde{z}, \eta, z) + (1 - weight)q^{new}(\alpha, \tilde{z}, \eta, z)$ where *weight* is a constant that is less than but close to 1 in order to dampen hog cycles.
7. Iterate prices until convergence and get equilibrium equity prices $q(\alpha, \tilde{z}, \eta, z)$.

To check the accuracy of the solution to the dynamic programming problem, we evaluate Euler equation residuals as described in Judd (1992). In order to do so, we solve for \hat{c} in the following equation:

$$q_t u'(\hat{c}_t) = \beta E_t[(q_{t+1} + d_{t+1})u'(c_{t+1})] \quad (24)$$

Intuitively, we solve for the consumption function that exactly satisfies the Euler equation implied by the solution of the dynamic programming problem. Then, we calculate $1 - (\hat{c}_t/c_t)$ which is a unitless measure of error. We find that the average Euler equation error (excluding the corner solutions) is 0.000459 for low degrees of informational asymmetry and as high as 0.0084 for

²⁰Domestic investors' and foreign investors' evaluate the same evolution for beliefs but their expectations of the next periods beliefs are different. Domestic investors' expectations about \tilde{z}_{t+1} are more precise than the foreigners' since domestic investors can calculate the distribution of d_{t+1} conditional on the true z_t .

signal-to-noise ratio of 0.25.²¹

Euler equation errors do not include the errors from the price iteration since Euler equation holds for any pricing function, not only the equilibrium price. As a measure for the accuracy of the equilibrium price, we report the tolerance of the price iteration. Tolerance is defined as the maximum of the absolute value of the difference between prices evaluated in the last two consecutive iterations, $\max\{|q^{new} - q^{old}|\}$. We iterate prices until tolerance is less than 0.0001.

5 Calibration

The parameter values used for the numerical solution are $\{\beta = 0.97, \sigma = 1.1\}$ for domestic households preferences, $\{R = 1.03\}$ for the risk free world interest rate, $\{a = 0.001, \theta = 0.1\}$ for foreign investors trading costs, $\omega = 0.5$ for the fraction of foreign investors, $\{\sigma_\eta = 0.0005, 0.001\}$ for the standard deviation of the additive i.i.d. shocks to dividends.²²

The values for the productivity shock are $\{z_H, z_L\} = \{0.1, 0.1 + 0.002\}$. These possible values and the transition probability matrix approximate a Normal AR(1) process $z_{t+1} = (0.0126) + (0.8757)z_t + \varepsilon_{t+1}$ where $std(\varepsilon) = 4.7881e - 004$.

6 Simulation

6.1 Full Information

In Figure (4), we plot simulated equity prices and productivity without informational frictions. Clearly, the swings in equilibrium equity prices match the swings in productivity and shocks to the transitory component of dividends have minimal effects on prices. A negative noise shock lowers the wealth of the domestic investors. In order to smooth consumption, domestic investors reduce their demand for equity, hence in equilibrium equity prices fall. However, this effect on prices is very small and not even visible in the figure. Foreign investors enjoy higher profits and respond to this shock only by responding to the slight drop in equilibrium price.

A nice feature of the model is its ability to account for the high volatility of equity prices relative to productivity as can be seen in figure (4). Given that productivity shocks are persistent

²¹Judd (1992) calls this measure a “bounded rationality measure” and interprets an error of 0.000459 as \$4 error made per \$10000 expenditure.

²²These standard deviations imply signal-to-noise ratios of 0.5 and 0.25 respectively.

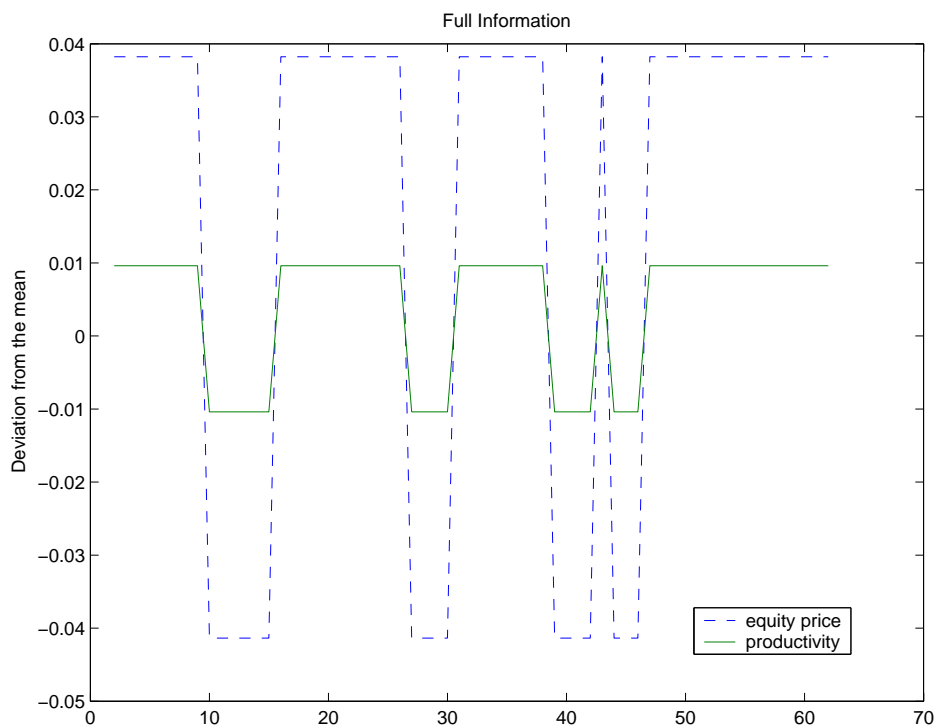


Figure 4: Full information

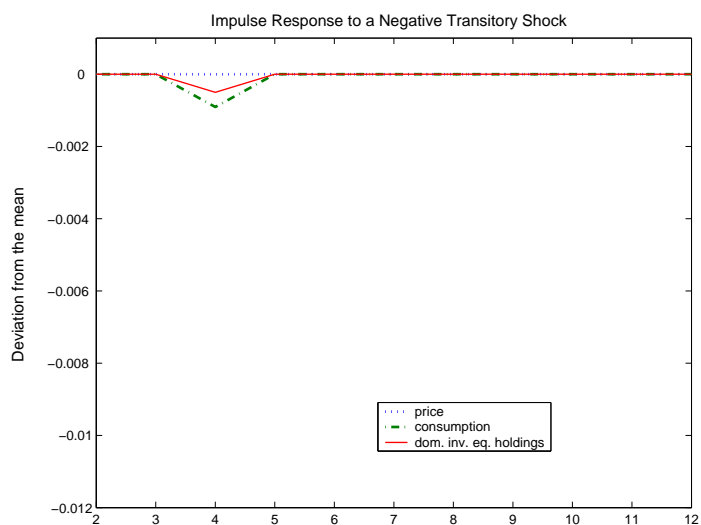


Figure 5: Impulse response to a two standard deviation negative transitory component shock

and this is common knowledge among investors, investors expect dividends to display persistence as well. The demand functions of domestic and foreign investors for equity depend on the expected present discounted value of future dividends. Therefore, expectations of higher dividends increase

the demand for equity resulting in an increase in equity prices. This is a standard result in asset pricing models where prices depend on future dividends.

In order to analyze the role of transitory component shocks in the full information economy, we plot the impulse response functions to a two standard deviation negative transitory component shock in Figure (5). Consumption and equity holdings of domestic investors fall due to the wealth effect mentioned above. The fall in prices however, is negligible.

6.2 Asymmetric Information

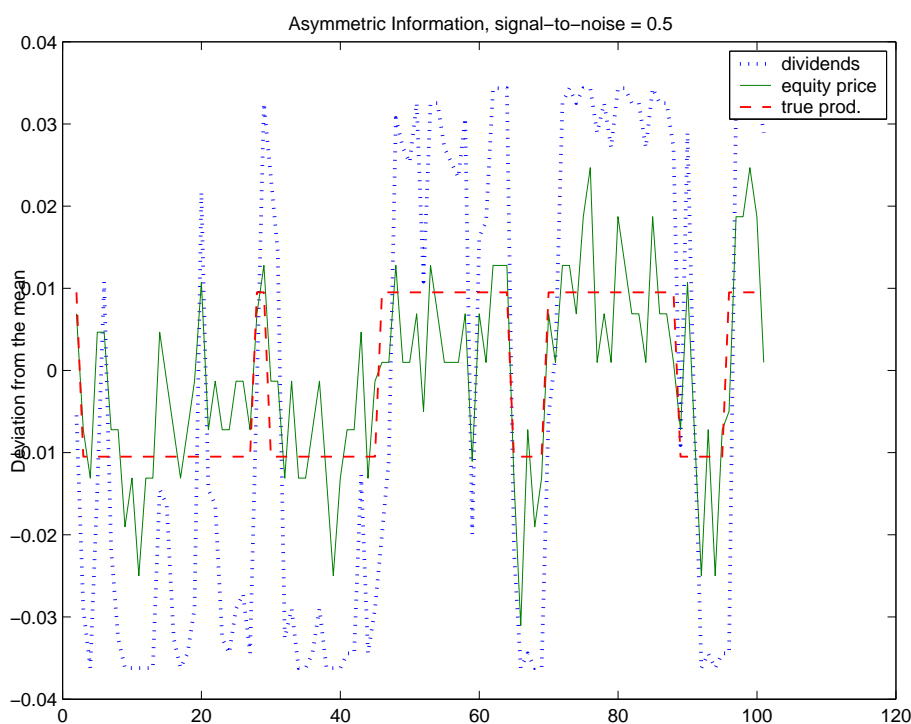


Figure 6: Signal-to-noise=0.50

In this section we introduce informational asymmetry. The parameters of the model and the size of the shocks are the same as the impulse responses demonstrated for the full information case. In figure (6) we plot simulated dividends, productivity and prices when the signal-to-noise ratio is 0.5.²³ Although beliefs usually follow the productivity closely, there are significant dis-

²³We plot the stationary distributions of beliefs for signal-to-noise ratios of 0.5 and 0.25 in figure (13). As the signal-to-noise ratio falls, the signals become less informative and hence the probability of beliefs being close to the true productivity falls.

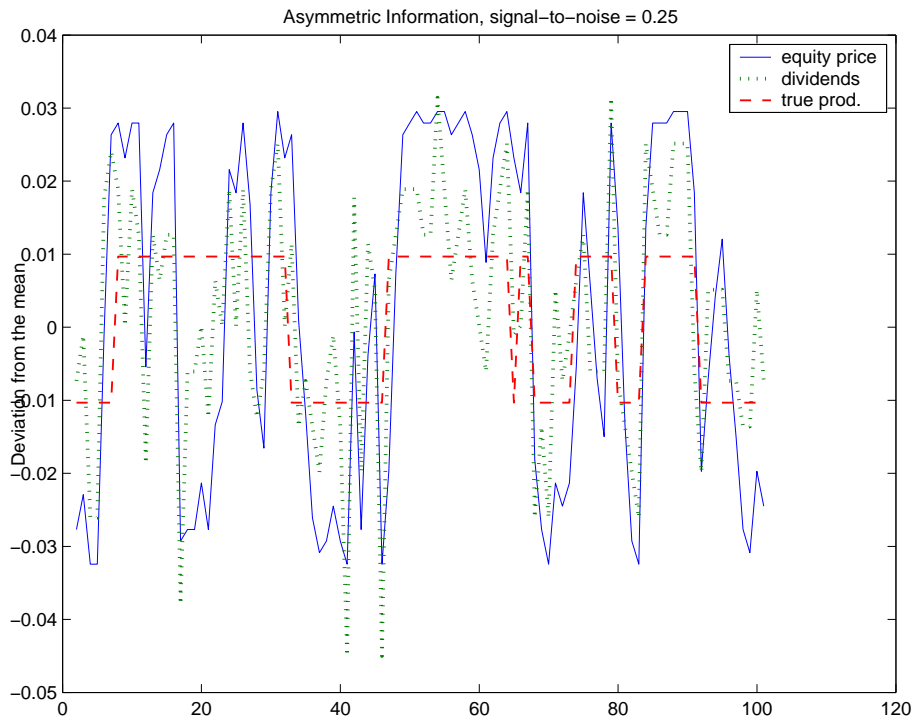


Figure 7: Signal-to-noise=0.25

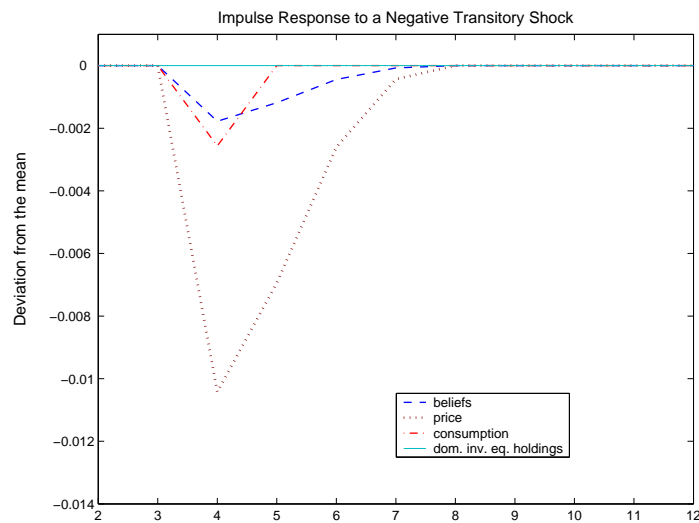


Figure 8: Impulse responses to a two standard deviation negative noise shock, signal-to-noise=0.25

crepancies between the two. For example, around period 15, misled by the high realizations of dividends, foreign investors turn optimistic about the economy although the true productivity is low. In figure (7) we plot the same series with a lower signal-to-noise ratio. The magnitude of

discrepancies between belief and the true productivity increase with the degree of informational asymmetry between domestic and foreign investors. In response to sufficiently low (high) realizations of the transitory component shocks, the economy experiences equity price busts (booms) that can be as large as the busts (booms) caused by productivity shocks.

Figure (8) shows the response of beliefs, prices, domestic investors' equity holdings and consumption to a 2 standard deviation noise shock to dividends. In period 3, foreign investors are optimistic about the economy. The negative shock in period 4 is sufficient for them to turn pessimistic and lower their demand. We find that the domestic investors however, do not change their equity positions since there are opposing forces that affect their decision that we explain soon.

Domestic investors' equity demand decision is affected through 2 channels in response to a negative transitory shock. The first one is due to lower dividend income. Negative transitory shocks decrease dividends and hence the wealth of domestic investors. This lowers the demand of domestic investors. This is the basic consumption smoothing effect and is present in the full information case as well.

The second effect is the capital gain opportunity for domestic investors using their informational advantage. When the equity is undervalued (overvalued) due to misperceptions of foreign investors, domestic investors know that this is a result of a transitory shock and in fact, prices will correct in the following period. As a result, they would like to use the opportunity to buy (sell) equity when the prices are low (high) due to pessimism (optimism) of foreign investors.

In the numerical exercise, we find that the relative magnitudes of the consumption smoothing motive and the capital gain incentives vary depending on whether the transitory shocks confirm or challenge the beliefs. If a negative transitory shock challenges the beliefs, then there is a larger adjustment in beliefs as well as prices. In these cases, the potential capital gain is high and the capital gain incentives are as large as the consumption smoothing incentives. Overall, domestic investors do not change their equity positions. In cases when the transitory shocks confirm the beliefs, neither beliefs nor the prices change significantly and the consumption smoothing effect dominates. Hence, they lower their demand for equity in response to a negative transitory component shock.²⁴

²⁴If there is a negative transitory component shock, equity is underpriced and domestic investors want to dissave in order to smooth consumption. We conjecture that if risk free bonds were available to the domestic investors in

Comparing figures (5) and (8) we see that the drop in consumption is larger in the asymmetric information case than the full information scenario. Since the domestic investors do not change their equity positions in response to the negative transitory shock, the shock is fully transmitted to consumption. There is a large price change due to this negative transitory shock.

After a two standard deviation shock foreign investors turn pessimistic and it takes about four periods for the effects of the shock to die off. Without imposing persistence exogenously, this informational friction is sufficient for the model to display persistence. The belief updating structure is the key element in the model that induces this persistence; previous periods beliefs are used in order to calculate the priors of the following period.

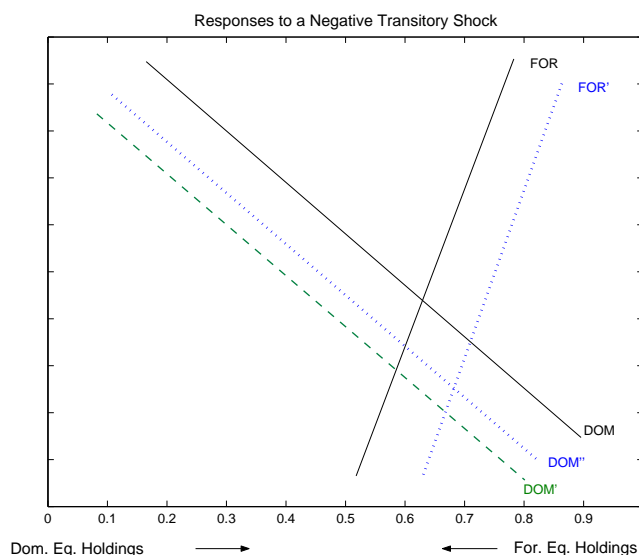


Figure 9: Static Analysis

We demonstrate the simple mechanism driving the movements in asset prices and equity holdings in figure (9) in a static framework. This figure explains the large price adjustments and small changes in the equity positions of investors in response to a negative transitory shock. The first shift (from DOM to DOM') of the domestic investors' demand is due to the consumption smoothing effect, the second one is due to their incentives to make capital gains (from DOM' addition to equity, they would be able to sell bonds for consumption smoothing purposes and they would choose to be net buyers of equity since equity is underpriced fully exploiting the capital gain opportunity. With risk free bonds, in response to a negative transitory shock, domestic investors would increase their demand for equity while foreign investors decrease. We conjecture that the adjustments in the equity holdings of the domestic investors would be larger.

to DOM''). Foreign investors' demand clearly shifts down (from FOR to FOR') as they turn pessimistic. The overall result is that prices drop sharply however, equity positions of investors do not change significantly.

6.3 Symmetric Information

In this section, we drop the assumption of asymmetric information and assume that both investors are equally uninformed. That is, domestic investors share the same information set with the foreign investors, and none of the investors observe the true values of the productivity. All investors solve the exact same signal extraction problem using the same signals (dividends). The main idea of this exercise is to investigate whether the results for the asymmetric information case hinge on the informational heterogeneity of investors. In other words, do the results change when the investors are equally uninformed and they “agree” on the state of the economy although this “agreed” state can be wrong?

In this set-up, dynamic programming problem of the domestic investors is:

$$\begin{aligned}
V(\alpha, \tilde{z}, d) = & \max_{\alpha'} \{u(c) \\
& + \beta [\Pr(z = z^H)\Pi(H, H) + Pr(z = z^L)\Pi(L, H)] \int V(\alpha', \phi(\tilde{z}, d'), d') f(d'|z' = z^H) dd' \quad (25) \\
& + \beta [Pr(z = z^H)\Pi(H, L) + Pr(z = z^L)\Pi(L, L)] \int V(\alpha', \phi(\tilde{z}, d'), d') f(d'|z' = z^L) dd'\}
\end{aligned}$$

for given prices $q(\alpha, \tilde{z}, d)$ where $Pr(z = z^H)$ is the probability assigned to productivity being high conditional on the information set. Computationally, the main differences between the asymmetric information set-up and this set-up are the true productivity is not a state variable and the probabilities assigned to each state are used in the calculation of $E[V(\alpha', \tilde{z}', d')]$.

Not being able distinguish the transitory shocks from the permanent ones makes the equity investment riskier for the domestic investors. On average, domestic investors demand less equity. In response to a positive transitory component shock, the domestic investors would like to buy equity in order to smooth consumption. However, their incentives to increase equity holdings are weaker than the asymmetric information set-up since they face the risk of being misled by a noisy signal. On average, their demand for equity is lower than the asymmetric information set-up. Unlike the asymmetric information setting, domestic investors do not have an informational advantage over their foreign counterparts and hence, they cannot make capital gains by better predicting the following period's prices.

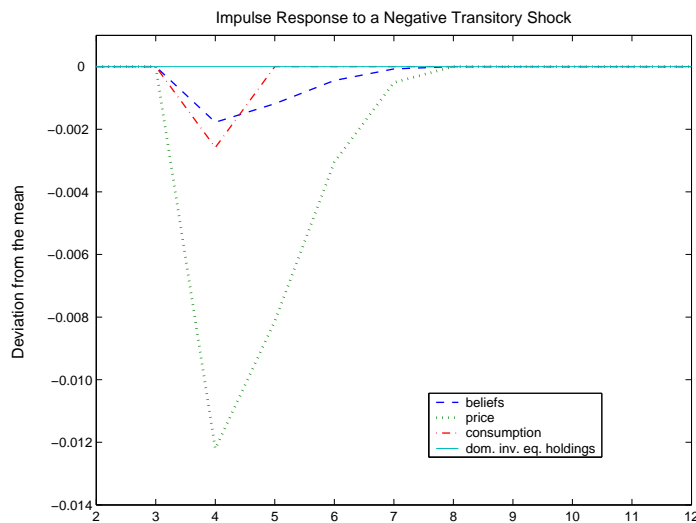


Figure 10: Impulse responses to a two standard deviation negative noise shock, symmetric information case signal-to-noise=0.25

Comparing figures (8) and (10) we see that dynamics of the model are fairly similar except the fact that price fall is slightly larger in the symmetric information scenario. This larger price drop can be explained by lower demand of domestic investors due increased riskiness.

7 From Miracles to Crises

In this section, we first compare the effects of positive and negative one period transitory component shocks of equal magnitude and then simulate an economy where a small negative shock can trigger a large downward adjustment in prices.

In our model, a negative and a positive shock of equal magnitude have fully symmetric effects on equity prices as displayed in figure (7). The reason behind this is the fact that there is no explicit mechanism in the model that will induce different dynamics for positive and negative signals.

An interesting observation from figure (7) is the cycle produced in response to a given negative (positive) shock is asymmetric in the sense that the initial bust (boom) is prompt and the correction afterwards is gradual for shocks larger than one standard deviation. A negative (positive) large transitory component shock induces abrupt under(over)-pricing of equity and it takes up to 5 periods for the effects of the shocks to be absorbed. This observation however, does not hold

for a shock that is as small as 0.7 standard deviation. The effects of a 0.7 standard deviation shock die out rapidly in one period and the asymmetry observed in response to larger shocks is absent for this magnitude.

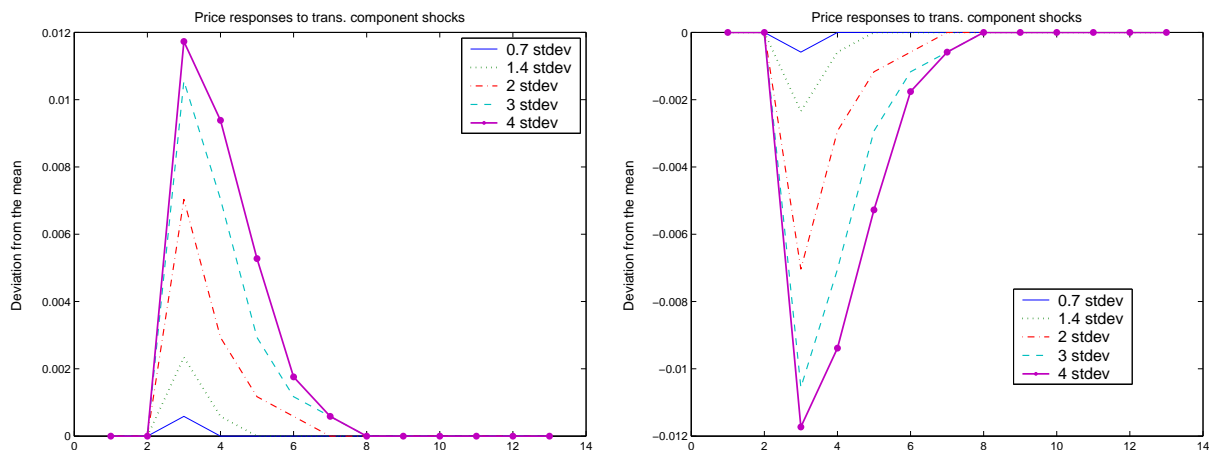


Figure 11: Price responses to one period positive and negative transitory component shocks.

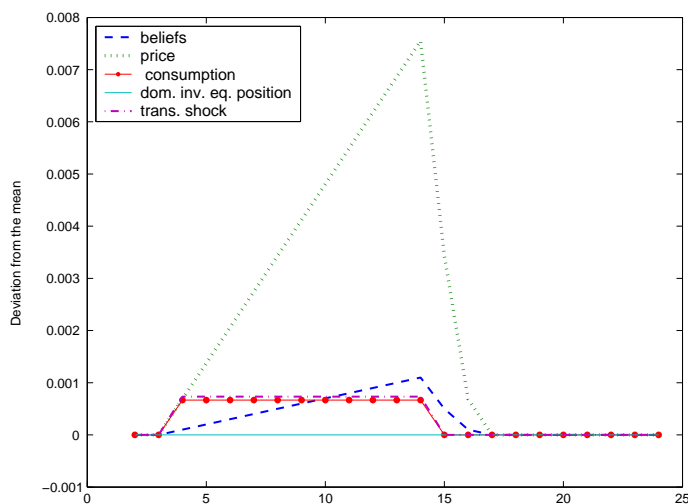


Figure 12: Impulse responses to 10 consecutive 0.7 std. transitory component shocks, signal-to-noise=0.25

To sum up, our model is able to produce abrupt falls and gradual recoveries in response to relatively large and negative transitory component shocks to dividends. One criticism of this result could be that emerging economies are not necessarily subject to large and negative shocks and in fact, usually fairly small shocks trigger large adjustments. We consider the following scenario in order to demonstrate a case where subsequent small shocks move the economy to

a vulnerable state. As this small positive shock comes to an end, an abrupt fall in prices is triggered.²⁵ With this exercise we intend to “replicate” a crisis in the sense that the economy enjoys a period of increasing investor confidence followed by a sudden loss of this confidence.

In figure (12), we plot the simulation results of this scenario. The consecutive positive (but as small as 0.7 standard deviation) signals start from period 3 and continue until 13. As foreign investors observe these slightly positive signals, they gradually build their confidence about the economy. In period 14, as positive signals come to an end, equity prices fall sharply. In fact, the trigger for the price drop is a change as in the transitory component which is small as a 0.7 standard deviation. However, this is enough for the investors to lose their confidence built in 10 periods. This exercise is an example where the vulnerability of the economy is in fact a *consequence* of the miracle period.

In conclusion, our model can produce abrupt adjustments in prices when (a) small positive transitory component shocks gradually increase investor confidence and prices fall sharply as these positive signals come to an end, (b) in the absence of preceding positive signals, the prices can fall sharply in response to a large negative signal and the recovery is gradual as displayed in figure (7).

8 Conclusion

This paper has developed an equilibrium asset pricing model with informational frictions in the form of asymmetric information between domestic and foreign investors where foreign investors have imperfect information regarding the true state of the economy. The model is able to account for the vulnerability of emerging economies after a period of high investor confidence and high asset prices. In addition, the model displays a disconnect between country fundamentals and asset prices, that is, the economy can have busts (booms) in equity markets even though the fundamentals of the economy are strong (weak). Asset prices display persistence in response to transitory shocks and the effects of the investors’ misperceptions are amplified.

We believe this paper sheds light on the incentives of emerging countries for following non-

²⁵This is similar in spirit with the second generation models of currency crises where the model displays multiple equilibria for a set of values of the fundamentals and the economy is “ripe for attacks” for this range of the fundamentals.

transparent policies. As we show in the paper, informational frictions that stem from opaque policies induce overpricing of assets in addition to underpricing. Given the risk aversion of domestic investors in this model, we can claim that the losses from a price fall will outweigh the gains from an equal amount of rise. However, if we were to add short-sighted policy-makers or some other irrationality, we could potentially show that it might be optimal for emerging economies to follow opaque policies.

Although the informational frictions introduced in this paper can produce large busts and booms in asset prices, there is a flaw. The booms and busts produced due to shifts in investor confidence are not larger than the business cycles. There are several modelling strategies to overcome this problem. One, and maybe the most promising, strategy would be introducing the informational frictions in a set-up like Aguiar and Gopinath (2004) where there are trend shocks to productivity. Alternatively, we can interpret the bad (good) states of the economy as crisis (non-crisis) rather than low (high) productivity that are in the magnitude of business cycles. This interpretation would potentially produce price adjustments as large as the ones observed during emerging market crises.

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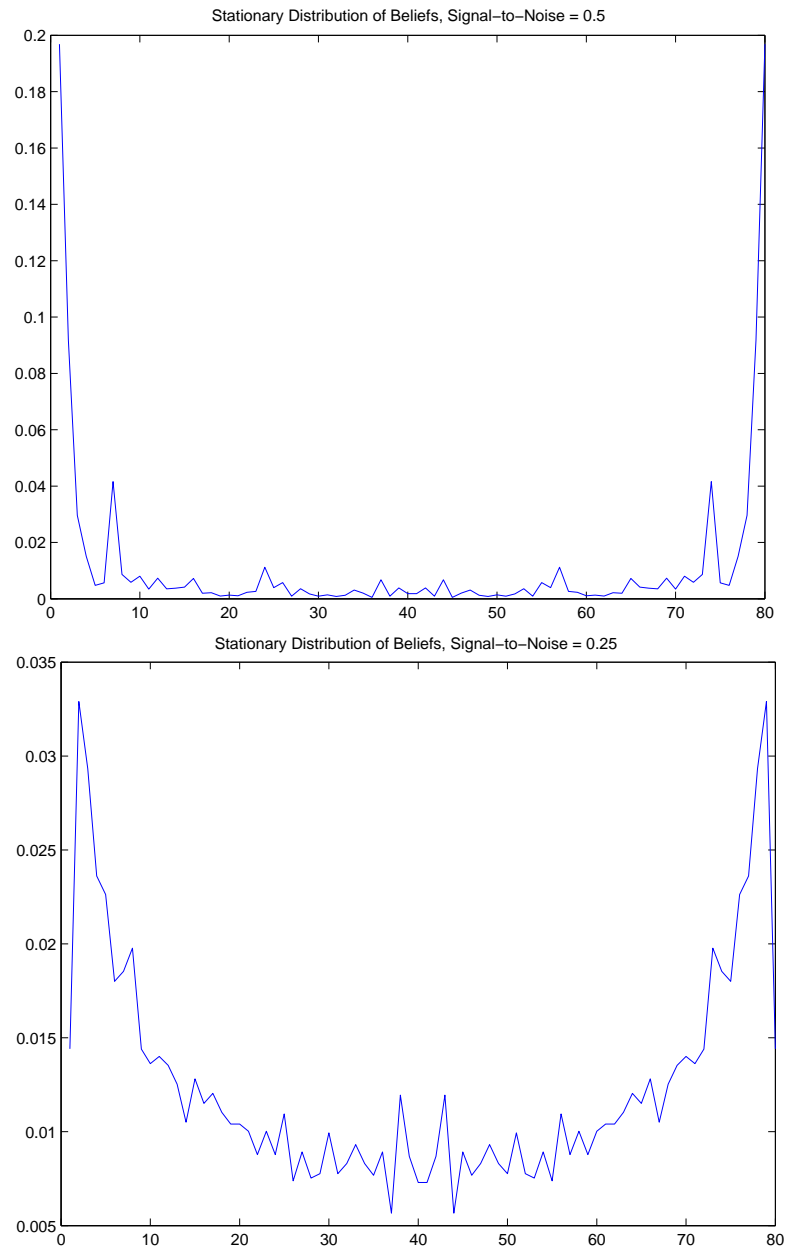


Figure 13: Stationary distribution of beliefs, signal-to-noise=0.5, 0.25