A Quantitative Model of Slow Recoveries from Financial Crises

Albert Queraltó
Federal Reserve Board
January 2013

Abstract

Financial crises tend to be followed by slow recoveries. Evidence from emerging market economies suggests an important role of labor productivity in accounting for the size and persistence of the output loss. This paper introduces a quantitative macroeconomic model consistent with these facts. The model features endogenous growth in total factor productivity through the adoption of new varieties of intermediate goods, and an agency problem in financial markets which implies that technology adopters may be credit constrained. A crisis shock generates declines in productivity, employment and output of size and persistence comparable to the data. The financial friction plays a quantitatively important role, explaining between a third and a half of the medium-run drop in output. Both endogenous growth and the financial friction substantially contribute to amplified movements in consumption and in the current account. The model’s transmission mechanism is shown to be especially sensitive to financial shocks.

*I wish to thank Mark Gertler for guidance and assistance throughout this project. I also thank Diego Comin, Jordi Galí, John Leahy, Virgiliu Midrigan, Vivian Yue and seminar participants at various venues for helpful comments. The views in this paper are solely the responsibility of the author and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

†Division of International Finance, Trade and Financial Studies. Email: albert.queralto@frb.gov
1 Introduction

Financial crises are frequently followed by slow recoveries. In their study of financial crises throughout history, Reinhart and Rogoff (2009) document that these types of episodes display the regularity that the post-crisis recovery is usually very weak. Recent research by Cerra and Saxena (2008) has provided further evidence corroborating this fact: by analyzing the behavior of output following episodes of financial crisis across a large set of countries, they conclude that there is little evidence of recovery following the crisis shock. In this paper, I first present evidence from crises in emerging market economies showing that an important part of the output decline associated with these episodes is due to a fall in labor productivity, which also displays considerable persistence. As shown in Section 2, productivity lost during financial crises tends not to be regained on average – if and when productivity growth resumes, it appears to do so from a level permanently below the pre-crisis trend.

The goal of this paper is to introduce a quantitative macroeconomic model that can explain the phenomenon of slow recoveries following financial crises. I argue that the findings described above pose a challenge to conventional explanations for the decline in measured labor productivity and total factor productivity (TFP) during financial crises, such as reduced capacity utilization or labor hoarding. While these mechanisms offer a reasonable account for the short-run declines in measured factor productivity, it is hard to imagine why they might persist into the medium run, once the crisis episode is over. Instead, this paper proposes to model explicitly medium-run productivity growth through the introduction of new technologies, and to illustrate how this process may be disrupted by a large shock and the ensuing financial distress. At the end of section 2, some evidence is presented which lends support to the mechanism proposed in the model, by examining the behavior of time series data on patents and trademarks during the crisis in South Korea in 1997.

In the model, described in Section 3, TFP growth arises endogenously through the adoption of new technologies. I use a formulation similar to Romer (1990), whereby endogenous growth results from the development and adoption of new varieties of intermediate goods. To motivate an imperfection in financial markets I use an approach similar to traditional “financial accelerator” models. In particular, I introduce a special class of agents, called entrepreneurs, who are assumed to be the only ones capable of introducing new varieties of intermediates. The activity of entrepreneurs consists of borrowing funds from households and from abroad to invest them in projects which, if successful, become usable designs for new intermediates. The financial friction takes the form of a limited enforcement problem between entrepreneurs and lenders, whereby at any point in time the entrepreneur can renegue on his debt and divert a certain fraction of his resources, at which point creditors can force
him into bankruptcy. The limited enforcement friction effectively introduces an endogenous constraint on entrepreneurial debt which potentially tightens as economic conditions worsen.

The mechanism just described is embedded in an otherwise reasonably conventional small open economy real business cycle model, modified to allow for variable capital utilization, habit formation in consumption and a working capital requirement which forces final goods producers to pay a fraction of the wage bill before production. These ingredients are relatively standard in the emerging markets business cycles literature. Although not critical for the main results regarding the lack of recovery from financial crises, which arise due to the novel mechanism linking technology adoption to financial frictions, these features help in making the short-run behavior of the model more realistic.

Section 4 presents a quantitative analysis of the model. The main experiment is meant as an illustration of how a crisis such as the one that occurred in East Asia in 1997, and the ensuing sharp deterioration in credit conditions, can generate the large and persistent decline in productivity observed in the data. The initiating disturbance is a shock to country risk. The interest rate increase, and the resulting drop in the values of adopted and unadopted technologies, generates a decline in entrepreneurial wealth, which increases the severity of the agency problem between entrepreneurs and their creditors. As a result, entrepreneurs’ constraints in their access to external finance tighten. The result at the macroeconomic level is a substantial reduction of the pace at which the entrepreneurial sector introduces new varieties of intermediates, leading aggregate TFP to drop permanently as a result.

The decline in TFP arising from the slowdown in the rate of technology adoption works to reduce aggregate labor demand. As a result, employment as well remains persistently depressed following the crisis, consistent with the empirical evidence. The magnitudes of the declines in output, productivity and employment produced by the baseline model are comparable to their empirical counterparts, documented in Section 2 below. The financial friction plays a quantitatively important role in amplifying the responses of these variables to the interest rate shock: for the baseline calibration, the degree of amplification is on the order of fifty percent. Further, as I show in a second experiment, the model can also be used to motivate a financial crisis through an intensification of the agency problem in financial markets, modelled as a reduction in the parameter that governs the amount of resources that creditors can expect to recover from a defaulting entrepreneur. Quantitative experiments illustrate that this type of disturbance works to further deepen the magnitude of the persistent declines in productivity, employment and output, thereby contributing to explain the slow recovery in a quantitatively significant way.

In a final set of experiments, I analyze the behavior of the model following two types of nonfinancial shocks: exogenous TFP shocks and wage markup shocks. The main result here
is that the transmission mechanism proposed in this paper is substantially less sensitive to these types of disturbances than it is to financial shocks. Thus, the model is also consistent with the evidence that prolonged slumps appear to be a phenomenon especially linked to financial crises.

**Related Literature.** As mentioned above, the evidence presented in this paper on the effects of financial crises on output, labor productivity and employment extends a recent paper by Cerra and Saxena (2008), who document that financial crises and other large negative shocks tend to have lasting effects on output. Using a similar methodology, I study the response of a decomposition of output into employment and labor productivity, finding a significant role for labor productivity in emerging economies. Other authors have documented large TFP losses in certain episodes of financial crisis, for example Meza and Quintin (2005), Kehoe and Ruhl (2009) or Pratap and Urrutia (2010). The results presented in this paper are consistent with theirs, and further show that productivity losses tend to be very persistent and are extensive to other episodes in other emerging countries.

The model developed in this paper follows Comin and Gertler (2006) in using the expanding variety formulation due to Romer (1990) to endogenize medium-run productivity dynamics. Comin and Gertler (2006) show that in the U.S. both TFP and R&D move procyclically at medium frequencies, and present a model that can account for short and medium term fluctuations in these and other variables. Comin, Loayza, Pasha and Serven (2009) also use an expanding variety formulation to model the diffusion of technologies from the U.S. to Mexico, and use their model to analyze how business fluctuations are interrelated in these two countries. These frameworks as well as mine share an emphasis on the importance of modelling business cycles and productivity growth as interrelated phenomena, a point that is reinforced by the evidence presented below showing a period of persistently lower productivity growth following financial crises. A similar point is emphasized by Fatás (2000a, 2000b), who documents a strong cross-country correlation between long-term growth rates and the persistence of output fluctuations – a natural outcome in a model featuring endogenous growth as shown in Fatás (2000a), and which is also consistent with the model studied in this paper.

The financial imperfection introduced in this paper builds on ideas from the literature on financial factors in macroeconomics, reviewed for example in Bernanke, Gertler and Gilchrist (1999) or Gertler and Kiyotaki (2010). This paper follows Gertler and Kiyotaki (2010) and others in modeling credit market imperfections through a limited enforcement problem. The main difference with more traditional “financial accelerator” models and the present paper is that here the credit market imperfection affects technology adoption, which is the ultimate source of productivity growth in the model economy. Aoki, Benigno and Kiyotaki (2007,
2009) also introduce a model with credit constraints in which a crisis can endogenously generate a drop in aggregate TFP, in their case because of productive units which are heterogeneous in their productivities: in their model, a crisis shock affects relatively more the more productive agents which leverage more than the less productive agents, and aggregate TFP declines as a result. Gopinath and Neiman (2011) present a model where the drop in imported varieties of goods that takes place during a large crisis generates declines in TFP. This paper differs from these other studies by emphasizing technology adoption in explaining medium-run TFP dynamics.

Finally, this paper is related to a growing literature on quantitative business cycle frameworks for emerging countries. Uribe and Yue (2006) and Neumeyer and Perri (2005) find an important role for fluctuations in interest rates and country risk in accounting for emerging market business cycles. Mendoza and Yue (2011) present a model which endogenizes fluctuations in country risk, by incorporating sovereign default within a business cycle framework. Their model also generates a drop in TFP during a crisis, due to a reduction in the use of imported inputs by firms. The main difference with the present paper in this respect is that here the goal is to account for the persistence of the fall in TFP following a crisis. Gertler, Gilchrist an Natalucci (2007) present a model featuring a financial accelerator designed to capture the Korean crisis in 1997-98, which they model as a country interest rate shock, and use their model to illustrate how a fixed exchange rate regime can exacerbate the crisis. Aguiar and Gopinath (2007) argue that what differentiates emerging markets from small developed economies is a more volatile and persistent nonstationary component of TFP, a hypothesis which the evidence presented in this paper lends support to. Further, this paper shows that such TFP process, which is assumed exogenously in Aguiar and Gopinath (2007), can be a natural result in a context in which TFP growth is endogenous and potentially affected by imperfections in financial markets.

The rest of the paper is organized as follows. In Section 2, I present the evidence on the effects of financial crises. In Section 3 I describe the model. In Section 4 I present numerical simulations of the model. Section 5 concludes.

2 Financial Crises and Productivity: Evidence

This section provides evidence on the medium-run dynamics of output following financial crises, and examines the extent to which they are driven by movements in employment and in labor productivity. I begin by showing that the Asian crisis in 1997 resulted in permanent output losses for the countries involved, largely driven by a permanent decline in labor productivity. I then go on to show, using more formal VAR methods, that this phenomenon is
quite general across episodes of banking crises in emerging economies. Finally, I present some
evidence on patents and trademarks, two indicators of technology innovation and adoption,\(^1\)
during the Korean 1997 crisis. The evidence shows large declines in both indicators during
the crisis, which also featured a very persistent decline in TFP relative to trend.

Figure 1 plots output, employment and labor productivity for a group of Asian countries
around the crisis episode of 1997. The countries included are Indonesia, Malaysia, Phillip-
ines, Korea, Thailand and Hong Kong, labelled “SEA-6”. I compute area totals by adding
constant dollar, PPP-adjusted GDP for each of the countries. Labor productivity is defined
as output per employed worker. All data are from the Total Economy Database.

The first panel of Figure 1 illustrates a very persistent output loss following the crisis:
trend output is not regained, but rather output growth appears to resume from a level per-
manently below the pre-crisis trend.\(^2\) Looking at the second and third panels, the behavior
of output appears to be driven largely by labor productivity, with a more modest slowdown
of employment growth.

Figure 2 examines more closely the behavior of labor productivity. The picture suggests
that productivity did not recover to its pre-crisis trend. As the second panel shows, it falls
by about 10% relative to trend and it never rebounds. This is robust to different choices for
the pre-crisis period\(^3\).

Next I extend the evidence in Cerra and Saxena (2008), who analyze the response of
output to financial crises, to investigate the roles of employment and labor productivity in
accounting for the output loss. I use a decomposition of real output \(Y_t\) into employment
\(L_t\) and labor productivity as follows:

\[
\log(Y_t) = \log\left(\frac{Y_t}{L_t}\right) + \log(L_t) = y_l t + l_t
\]

where \(y_l t \equiv \log\left(\frac{Y_t}{L_t}\right)\) and \(l_t \equiv \log(L_t)\). Following Cerra and Saxena (2008), I estimate the
following panel VAR:

\[
x_{i,t} = a_i + \sum_{j=1}^{4} A_j x_{i,t-j} + \sum_{s=0}^{4} B_s D_{i,t-s} + \epsilon_{i,t}\tag{1}
\]

\(^1\)See Griliches (1990) and Jaffe and Trajtenberg (2002) for discussions on patents as indicators of tech-
nological change, and Yorukoglu (2000) for an example of work using trademarks data.

\(^2\)the pre-crisis trend is calculated as a linear trend for the period 1980-1996.

\(^3\)The annualized growth of labor productivity for the period 1980-1996 is 4.06%, which is close to that for
the entire pre-crisis sample (1960-1996), equal to 3.69%. Annualized productivity growth for the post-crisis
period of 1998-2007 is 3.61%.
where

\[ x_{i,t} = \begin{bmatrix} \Delta y_{i,t} \\ \Delta n_{i,t} \end{bmatrix} \]

\( D_{i,t} \) is a dummy variable indicating a banking crisis during year \( t \) in country \( i \), and \( a_i \) is a country fixed effect. I estimate equation (1) using banking crisis indicators, on data for a group of emerging economies.\(^4\) I use the same crisis indicators as Cerra and Saxena (2008), who obtain banking crisis indicators from Caprio and Klingebiel (2003): a banking crisis is an episode in which a large fraction of bank capital is exhausted. Yearly data on real output and employment for the period 1950-2005 is from the Total Economy database.

Figure 3 contains impulse responses of output, labor productivity and employment, together with one-standard-error bands. The first row echoes the results in Cerra and Saxena (2008): banking crises episodes involve large and persistent losses in output, which falls by about 8% as a result of the crisis, with little evidence of recovery. The decomposition of output into labor productivity and employment uncovers a large drop in labor productivity, of about two thirds of the decline in output at the trough, which is also highly persistent. As the third panel shows, financial crises also involve persistent declines in employment.

Finally, Figure 5 displays time series on TFP and patent and trademark applications by residents in South Korea. As shown in the top left panel, the 1997 financial crisis involved a persistent slowdown in TFP relative to trend. From the bottom left panel, after a moderate slowdown prior to the crisis, in 1997 TFP plunges by about 6% relative to trend. Consistent with the evidence just presented, this decline is never recovered. The right top and bottom panels show patent and trademark applications in Korea. After rising for almost two decades practically without interruption, both indicators suffered large declines during the crisis episode, of about 25% for patents, and more than 35% in the case of trademarks. Further, in the case of patents the decline is considerably persistent. This evidence lends support to the mechanism introduced in this paper, namely that a large external shock such as the one suffered by South Korea in 1997, and the financial sector problems resulting from it, may lead to a reduction in the pace at which the economy introduces and adopts new technologies, which results in a permanent TFP loss. Such effects of finance on technology are consistent with results found by other authors such as Kortum and Lerner (2000) and Kerr and Nanda (2009), for the case of the US.\(^5\) The hypothesis that difficult access to external finance hinders technology innovation and adoption activity is also supported by

\(^4\)See appendix A for a list of the countries used in the analysis and details on the data.

\(^5\)Kortum and Lerner (2000) establish a positive effect on innovation of the availability of venture capital funding, and Kerr and Nanda (2009) show that US financial reforms enhanced the process of small firm entry.
several firm-level studies – see Hall (2002) and Hall and Lerner (2009) for surveys of work using data from OECD countries. There is also substantial evidence documenting such effects for developing economies: see Ayyagari et. al. (2007), and particularly Gorodnichenko and Schnitzer (2010), for studies using firm-level survey data from developing economies.

The evidence described above confirms that the large productivity drop associated with financial crises in emerging countries is indeed a general phenomenon across episodes and countries. The magnitudes uncovered by the exercise are comparable to those found by other authors, such as Meza and Quintin (2005) or Kehoe and Ruhl (2009). Further, these productivity drops tend to have a very large permanent component in emerging markets, lending support to the hypothesis put forward by Aguiar and Gopinath (2007) that in these countries “the cycle is the trend”. There is also some evidence suggesting that the behavior of TFP can be related to technological factors. In the following sections I introduce a quantitative model that is capable of generating drops in TFP and productivity of size and persistence comparable to those in the data, thereby accounting for slow recoveries following financial crises, and I show that frictions in the financing of the adoption of new innovations contribute to a substantial degree in accounting for these drops.

3 The Model

The core framework is a small open economy model with endogenous TFP growth through an expanding variety of intermediates, as in Romer (1990) and Comin and Gertler (2006). The difference with respect to these frameworks is that there is an imperfection in financial markets in the form of costly enforcement that impedes the smooth flow of resources from savers (households and international investors) to entrepreneurs, who are the agents with the ability to introduce new intermediates. I introduce three further modifications that have become common in the DSGE literature recently, and that help the model produce a more realistic behavior of macrconomic aggregates in response to the crisis: variable capital utilization, habit formation in consumption, and a working capital requirement on intermediate goods producers.

As in familiar “financial accelerator” models, frictional credit markets generates an amplification effect, inducing a greater slowdown in adoption activity relative to a benchmark without financial frictions. The rise in country interest rates, and the consequent fall in the value of the assets controlled by entrepreneurs (adopted and unadopted technologies) worsen the agency problem between entrepreneurs and lenders and reduce the flow of credit to entrepreneurs, implying a decline in new technology investments relative to the frictionless benchmark.
There are six types of agents in the model: households, entrepreneurs, innovators, capital producers, intermediate goods producers and final goods producers. Final output is produced by the latter using an expanding variety of intermediates. The entrepreneurial sector purchases innovations, interpretable as “unadopted” technologies, using funds borrowed from abroad and from domestic households. If successfully adopted, an innovation becomes a new variety of intermediate. In what follows, I discuss the behavior of each of these agents in turn, and derive the aggregate relationships that characterize the balanced growth path of the model economy.

3.1 Households

Suppose there is a representative family with a unit measure of members. Households make decisions on consumption, labor supply, investment in physical capital and saving through a risk-free international bond. There are two types of members within each household: workers and entrepreneurs, with measures $f$ and $(1 - f)$ respectively. A fraction of the workers are specialized or “skilled” workers, and supply labor inelastically to the innovation sector. Their role will be clear as I discuss innovators below. Regular workers supply labor elastically to intermediates producers. Both types of labor return wages to the family. Entrepreneurs have the ability of adopting new types of intermediates, and also transfer any earnings from this activity back to the household. The following subsection describes the activity of entrepreneurs in detail. There is perfect consumption insurance among family members. As in Gertler and Kiyotaki (2010), this formulation is a simple way of introducing heterogeneity in terms of borrowers and lenders while maintaining the tractability of a representative agent model.

There is random turnover between entrepreneurs and workers: an entrepreneur becomes a worker with probability $(1 - \sigma)$. At the end of their careers, entrepreneurs transfer to the family the value of the assets they have accumulated. At the same time, each period a fraction $(1 - \sigma)\frac{1}{1 - f}$ of workers start a career as entrepreneurs, exactly offsetting the number of entrepreneurs who exit. As explained below, it is assumed that the family transfers a small amount of resources to entrepreneurs who start out so they are able to start operations. Entrepreneur exit is introduced as a device to ensure that the financial imperfection will be relevant: otherwise entrepreneurs might reach a point where internal resources are enough to finance all desired investments in new technology.

Letting $C_t$ denote consumption and $L_t$ hours of work in the sector producing intermediates, a households’ utility function is
The preference structure follows Uribe and Yue (2006), Neumeyer and Perri (2005) and much of the emerging market business cycle literature. It abstracts from wealth effects on labor supply, as in Greenwood, Hercowitz and Huffman (GHH, 1988). The term multiplying the disutility of work, $\Gamma_t$, depends on the aggregate technological level, $A_t$, as follows:

$$\Gamma_t = A_t^{\gamma} \Gamma_{t-1}^{1-\gamma}$$

The term $\Gamma_t$, which at the low frequency grows at the same rate as $A_t$, is introduced to ensure the existence of a balanced growth path with stationary hours. In the calibrated version of the model, I will set $\gamma$ to a very small value, so that fluctuations in $A_t$ have a negligible impact on the disutility of labor at high and medium frequencies. Under the interpretation of GHH preferences as a reduced form for an economy with home production (Benhabib, Rogerson and Wright (1991) ), a small value of $\gamma$ can be viewed as capturing a process of “slow diffusion” of the technologies used in the final goods sector into the home production sector.

The households’ decision problem is to choose stochastic sequences for consumption, labor supply, purchases of the international bond and purchases of following-period physical capital to solve the following problem:

$$\max_{(C_i, L_i, D_{Fi}, K_{i+1})} \mathbb{E}_t \sum_{i=0}^{\infty} \beta^i u(C_{t+i}, L_{t+i})$$

subject to

$$C_t + P_{K,t} K_{t+1} \leq R^k_t K_t + W_t L_t + \frac{1}{R_t} D^F_t - D^F_{t-1} + \tau_t$$

Above, $P_{K,t}$ is the price of capital and $R^k_t$ is its rental rate, $W_t$ the wage rate and $R_t$ is the interest rate on the international bond. $D^F_t$ denotes the family’s choice of foreign debt and $K_{t+1}$ is the choice for physical capital holdings. Finally, $\tau_t$ denotes net transfers from firm ownership plus wages earned by skilled workers.

The international interest rate $R_t$ depends on total net foreign indebtedness $B_t$, equal to the sum of household and entrepreneurial debt, and on a random shock $r_t$ as follows:

$$R_t = r + e^{rt} + \psi \left[ e^{\frac{B_t - B_{t-1}}{T}} - 1 \right]$$

As is usual in the small open economy literature, the reason for introducing a dependence of the cost of borrowing on net foreign indebtedness is to ensure stationary dynamics. I choose
a very small value for $\psi$ so that this feature does not affect the dynamics of the model. A raise in $r_t$, interpretable as a country interest rate shock, is a simple way to model the sudden capital outflows that appear to be the trigger of many of the emerging market financial crises analyzed in the previous section.

The expression for marginal utility of consumption, $U_{C,t}$ is the following:

$$U_{C,t} = u_{C,t} - \beta \gamma E_t (u_{C,t+1})$$

$$u_{C,t} = \left( C_t - h C_{t-1} - \Gamma_t \frac{1}{1 + \epsilon} L_t^{1+\epsilon} \right)^{-\rho}$$

Define the households’ stochastic discount factor between periods $t$ and $t + i$, $\Lambda_{t,t+i}$ as

$$\Lambda_{t,t+i} \equiv \frac{\beta U_{C,t+i}}{U_{C,t}}$$

Then the household’s decision on bond and capital holdings are characterized by two conventional Euler equations:

$$1 = E_t (\Lambda_{t,t+1}) R_t$$

$$1 = E_t \left( \Lambda_{t,t+1} \frac{R_{t+1}^k}{P_{K,t}} \right)$$

Labor supply is given by

$$u_{C,t} \Gamma_t L_t^\epsilon = U_{C,t} W_t$$

3.2 Entrepreneurs

The activity of entrepreneurs consists in introducing new varieties of intermediate goods. Specifically, entrepreneurs use borrowed funds to purchase potential designs for new intermediates. These “innovations” are interpretable as potential new technologies that have not yet been implemented in the economy, and which may be entirely novel or possibly adaptations of technologies already in use in more advanced countries.\footnote{In the latter case, the assumption is that it is still costly to introduce an innovation that is already in use in a more developed economy. See Mansfield, Schwartz and Wagner (1981) for evidence suggesting that “imitation” costs can indeed be substantial.} Unadopted innovations sell at price $J_t$. The innovations that entrepreneurs purchase are not yet usable for production however, and entrepreneurs are the only agents with the ability to turn them into designs
for marketable new intermediates, or “adopt” them. The adoption technology is very simple: any unadopted project that the entrepreneur is holding becomes a usable design with probability $\lambda$ each period. Innovations are subject to the risk of (exogenously) becoming obsolete: $1 - \zeta$ represents the probability of obsolescence. Once an entrepreneur is successful in adopting an innovation, he then sells the newly adopted technology to a monopolist, who then proceeds to start manufacturing the new good and sell it to final goods producers. The price at which successfully adopted technologies sell is denoted $v_t$. It will be made clear below how $v_t$ is determined.

The agency friction in financial markets takes the form of a limited enforcement problem between the entrepreneur and his creditors: at the end of the period, after borrowing funds, an entrepreneur can default on his debt and divert a fraction $\theta$ of his resources, with creditors only being able to recover the remaining part $1 - \theta$. This imposes a limit on how much debt the entrepreneur is able to take on ex-ante, as lenders recognize that excessive debt will lead to default.

In what follows I formally describe an entrepreneur’s problem. The objective of the entrepreneur is to choose state-contingent sequences of purchases of innovations and borrowing in capital markets to maximize expected terminal wealth (recall that an entrepreneur exits each period with iid probability $\sigma$, at which time it pays out any accumulated wealth to the family that it comes from). The entrepreneur’s wealth consists of the revenues obtained from selling successful adoptions as well as unadopted innovations, net of debt. The entrepreneur’s choice is subject to a budget constraint and a no-default constraint, where the no-default constraint forces the entrepreneur’s continuation value to be greater than the default payoff – creditors realize that if this were not the case, the entrepreneur would default on his debt. The formal statement of the entrepreneur’s sequence problem is the following:

$$\max_{\{s_{t+i-1}, d_{t+i-1}\}_{i=1}^\infty} \left[ E_t \sum_{i=1}^{\infty} \sigma^{i-1} (1 - \sigma) A_{t+i} \left\{ \left[ \lambda v_{t+i} + (1 - \lambda) \zeta J_{t+i} \right] s_{t+i-1} - R_{t+i-1} d_{t+i-1} \right\} \right]$$

subject to

$$J_t s_t + R_{t-1} d_{t-1} \leq \left[ \lambda v_t + (1 - \lambda) \zeta J_t \right] s_{t-1} + d_t$$

(11)

(12)
\[
\mathbb{E}_t \sum_{i=1}^{\infty} \sigma^{i-1}(1 - \sigma)\Lambda_{t,i+1} \{[\lambda v_{t+i} + (1 - \lambda)\zeta J_{t+i}] s_{t+i-1} - R_{t+i-1} d_{t+i-1} \} \geq \theta J_t s_t
\]  

(13)

From the budget constraint, equation (12), the entrepreneur finances the purchase of a measure \(s_t\) of innovations, which costs \(J_t s_t\), and debt repayments, \(R_{t-1} d_{t-1}\), with the revenues obtained from previous innovation attempts as well as with new debt issues. From the innovations that the entrepreneur attempted adopting the previous period, \(s_{t-1}\), fraction \(\lambda\) are successfully adopted during period \(t - 1\), and fraction \(1 - \lambda\) remain unadopted. The innovations that are adopted can be sold to monopolists at price \(v_t\), while those that remain unadopted can be sold in the market for unadopted innovations at price \(J_t\), provided that they survive obsolescence. As indicated by equation (11), if an entrepreneur alive at \(t\) exits in period \(t + i\) (which happens with probability \(\sigma^{i-1}(1 - \sigma)\) ) he or she returns the accumulated wealth back to the household. Thus, an entrepreneur values payoffs in the period and state at which he exits with the household’s stochastic discount factor, \(\Lambda_{t,t+i}\).

Equation (13) is the entrepreneur’s incentive constraint. At the end of period \(t\), after having borrowed in capital markets, the entrepreneur may choose to default on his creditors and divert fraction \(\theta\) of available funds, which he then transfers back to the household of which he is a member. Creditors can then force the entrepreneur into bankruptcy and recover the remaining fraction \(1 - \theta\) of resources, but it is too costly for them to recover the fraction \(\theta\) of funds that the entrepreneur diverted. Accordingly, for creditors to be willing to supply funds to the entrepreneur, equation (13) must hold: the entrepreneur’s value if he honors his contract with his creditors must be greater than the value of diverting resources in the amount \(\theta J_t s_t\) and being shut down.

To simplify the entrepreneur’s problem, define first the rate of return to one dollar invested in technology adoption, \(R_{Z,t}\):

\[
R_{Z,t} = \frac{\lambda v_t + (1 - \lambda)\zeta J_t}{J_{t-1}}
\]

\(R_{Z,t}\) depends only on the aggregate state, through prices \(v_t\) and \(J_t\). Times of low realizations of the values of adopted and unadopted technologies, \(v_t\) and \(J_t\), will be times of low returns \(R_{Z,t}\). Noting that an entrepreneur’s individual state variables at the beginning of period \(t\) are \(s_{t-1}\) and \(d_{t-1}\), the entrepreneur’s problem can be expressed recursively as follows:
\[ V_t(s_{t-1}, d_{t-1}) = \max_{s_t, d_t} \left( 1 - \sigma \right) \mathbb{E}_t [\Lambda_{t,t+1} (R_{Z,t+1} J_t s_t - R_t d_t)] + \sigma \mathbb{E}_t [\Lambda_{t,t+1} V_{t+1}(s_t, d_t)] \quad (14) \]

subject to

\[ J_t s_t + R_{t-1} d_{t-1} \leq R_{Z,t} J_{t-1} s_{t-1} + d_t \quad (15) \]

\[ (1 - \sigma) \mathbb{E}_t [\Lambda_{t,t+1} (R_{Z,t+1} J_t s_t - R_t d_t)] + \sigma \mathbb{E}_t [\Lambda_{t,t+1} V_{t+1}(s_t, d_t)] \geq \theta J_t s_t \quad (16) \]

Above, the time index on the value function reflects aggregate uncertainty. The problem can be simplified further by realizing that the key individual state variable will be the entrepreneur’s net worth \( w_t \), defined as the value of his assets (his purchases of innovations) minus his debt:

\[ w_t \equiv J_t s_t - d_t \quad (17) \]

As shown below, net worth is the key individual state variable because it will determine the incentives for entrepreneurs to default. From the budget constraint (15) at equality, the evolution of net worth is

\[ w_t = (R_{Z,t} - R_{t-1}) J_{t-1} s_{t-1} + R_{t-1} w_{t-1} \quad (18) \]

Net worth at \( t \) is given by the gross return to technology adoption activity financed during \( t-1 \), net of repayments to creditors. Equation (18) shows that net worth at \( t \) depends on the individual state at \( t-1 \) \((s_{t-1}, w_{t-1})\) together with the realization of the aggregate state at \( t \), through the rate of return \( R_{Z,t} \). This suggests making the following guess for the entrepreneur’s value function:

\[ V_t(s_{t-1}, d_{t-1}) = \Omega_t w_t \quad (19) \]

where the undetermined coefficient \( \Omega_t \) is conjectured to depend only on the aggregate state. Define also the following variables:

\[ \Omega_{t+1} \equiv 1 - \sigma + \sigma \Omega_{t+1} \quad (20) \]

\[ \mu_t \equiv \mathbb{E}_t [\Lambda_{t,t+1} \Omega_{t+1} (R_{Z,t+1} - R_t)] \quad (21) \]
\[ \nu_t \equiv E_t (\Lambda_{t,t+1} \Omega_{t+1}) R_t \]  (22)

Variable \( \Omega_{t+1} \) is interpretable as the prospective value of a unit of net worth, before the entrepreneur finds out whether he will have to exit at the end of the period or not. From equation (21), \( \mu_t \) is interpretable to the return for the entrepreneur of investing in technology adoption in excess of the cost of funds. Finally, \( \nu_t \) represents the value of an extra unit of net worth today.

With these definitions, the problem of the entrepreneur reduces to the following:

\[ \Omega_t w_t = \max_{s_t} \mu_t J_t s_t + \nu_t w_t \]  (23)

subject to

\[ \mu_t J_t s_t + \nu_t w_t \geq \theta J_t s_t \]  (24)

Note that, as discussed above, \( \mu_t \) represents the value to the entrepreneur of funding an additional project (increasing \( s_t \)) while holding net worth constant. On the other hand, \( \nu_t \) is the value of an additional unit of net worth, holding constant \( s_t \). With frictionless financial markets entrepreneurs would be unconstrained, with the implication that \( \mu_t = 0 \). The agency problem introduces a friction that makes entrepreneurs potentially constrained in their activity of financing technology adoption projects, which may place limits on this arbitrage.

Equation (24) is the incentive constraint. Note that as long as \( \mu_t \geq 0 \), it is profitable for the entrepreneur to borrow and fund an additional project. Thus, in this instance, and given \( w_t > 0 \), the constraint binds:

\[ J_t s_t = \frac{\nu_t}{\theta - \mu_t} w_t \]  (25)

Equation (25) shows that the amount the entrepreneur can spend on funding projects, \( J_t s_t \), is constrained by his net worth \( w_t \), through a limit on the amount the entrepreneur is allowed to borrow in capital markets.\(^7\)

Define the entrepreneur’s maximum leverage ratio \( \phi_t \) as

\[ \phi_t \equiv \frac{\nu_t}{\theta - \mu_t} \]  (26)

\(^7\)Note that for the constraint to bind we must also have \( \mu_t < \theta \): otherwise, the value to the entrepreneur of an extra project is greater than the gain from diverting funds, so the incentive constraint does not bind. In the equilibrium constructed below, for reasonable parameterizations the constraint will always be binding along the balanced growth path.
so that when the credit constraint binds,

\[ J_t s_t = \phi_t w_t \]  \hspace{1cm} (27)

Then with a binding constraint, solving the undetermined coefficient from (23)-(24) we have that

\[ \Omega_t = \mu_t \phi_t + \nu_t \]  \hspace{1cm} (28)

The value of a unit of net worth today (\( \Omega_t \)) derives from its value holding assets constant (\( \nu_t \)) plus the capacity that it generates to fund additional projects (\( \phi_t \)) multiplied by the value to the entrepreneur of those additional projects (\( \mu_t \)).

**Aggregation.** Linearity of (27) makes aggregation simple: the aggregate amount of projects financed by entrepreneurs, \( S_t \), is constrained by aggregate net worth of the entrepreneurial sector:

\[ J_t S_t = \phi_t W_t \]  \hspace{1cm} (29)

At the same time, aggregate net worth at \( t \) is given by the sum of net worth of surviving entrepreneurs, which evolves individually according to (18), and the transfer that newborn entrepreneurs obtain from their family. For simplicity I assume that the transfer is a small fraction \( \xi \) of the total value of the projects funded the previous period. Accordingly, the law of motion of aggregate net worth is given by

\[ W_t = \sigma \left[ (R_{Z,t} - R_{t-1}) + R_{t-1} W_{t-1} \right] J_{t-1} S_{t-1} + (1 - \sigma) \xi J_{t-1} S_{t-1} \]  \hspace{1cm} (30)

Note that an important source of fluctuations in aggregate net worth of the entrepreneurial sector are variations in returns \( R_{Z,t} \), which as discussed above arise from movements in the prices of adopted and unadopted technologies, \( v_t \) and \( J_t \).

In what follows I describe the evolution of the aggregate stock of adopted and unadopted technologies. At the beginning of period \( t \), a total number of innovations \( Z_t \) exist in the economy. Each point in \([0, Z_t]\) represents a potential new technology. The points between 0 and \( A_t \) correspond to already adopted technologies, with \( A_t < Z_t \). In period \( t \), the innovation sector (described in the following subsection) introduces a measure \( Z_{N,t} \) of new potential technologies. At the same time, a fraction \( 1 - \zeta \) of total technologies becomes obsolete. Thus, the aggregate number of innovations \( Z_t \) evolves as follows:

\[ Z_{t+1} = \zeta Z_t + Z_{N,t} \]  \hspace{1cm} (31)
Therefore, in period $t$ the points between $A_t$ and $\zeta Z_t + Z_{N,t}$ correspond to technologies “in process”, i.e. projects that the entrepreneurial sector is currently attempting to adopt. A fraction $\lambda$ of these projects will become adopted during period $t$. The total number of adopted technologies then evolves as follows:

$$A_{t+1} = \lambda [\zeta Z_t + Z_{N,t} - A_t] + \zeta A_t$$  \hspace{1cm} (32)

where the term in brackets is the stock of products that have not yet been converted.

Recall that $S_t$ refers to the aggregate number of potential technologies that the entrepreneurial sector purchases and attempts to adopt. It follows that in equilibrium, we must have

$$S_t = \zeta Z_t + Z_{N,t} - A_t$$  \hspace{1cm} (33)

That is, the total number of projects that entrepreneurs are currently holding and trying to develop, must be equal to the total number of unadopted projects in the economy.

These considerations clarify how financial factors may affect the evolution of TFP. When net worth is low, through equation (29) the aggregate number of unadopted projects that the entrepreneurial sector is attempting to adopt, $S_t$, is reduced. This makes demand for new innovations $Z_{N,t}$ lower, as equation (33) suggests. With a smaller number of products being attempted to adopt, the growth rate of TFP will decline, as equation (32) indicates.

**The Frictionless Benchmark.** As emphasized above, with frictionless markets there is perfect arbitrage, so that excess returns $\mu_t$ must be equal to zero. It follows from (20)-(22) and (28) that $\mathbb{E}_t(\Lambda_{t,t+1} R_{Z,t+1}) = \mathbb{E}_t(\Lambda_{t,t+1}) R_t = 1$, or

$$J_t = \mathbb{E}_t\{\Lambda_{t,t+1} [\lambda v_{t+1} + (1 - \lambda)\zeta J_{t+1}]\}$$  \hspace{1cm} (34)

Comin and Gertler (2006) derive a similar equation for optimal adoption. With financial frictions and constrained adoption, we will have

$$J_t < \mathbb{E}_t\{\Lambda_{t,t+1} [\lambda v_{t+1} + (1 - \lambda)\zeta J_{t+1}]\}$$  \hspace{1cm} (35)

The gap between the left and right hand side of (35) widens whenever entrepreneurs’ financial constraints tighten, and at the same time the rate of technology adoption falls below its frictionless level. The imperfection in financial markets also implies that the growth rate of TFP, and therefore of output, along the balanced growth path will be below its value in
a model without financial frictions.\textsuperscript{8}

\section*{3.3 Innovators}

The innovations that entrepreneurs purchase and attempt to turn into designs for usable intermediates are produced in a competitive sector that uses final output and skilled labor, interpretable as scientists or engineers, as inputs. Specifically, this sector has access to the following production function:

\[ Z_{N,t} = N^\eta (A_t L_{S,t})^{1-\eta} \] (36)

(36) indicates that an innovator using \( N_t \) units of final output and \( L_{S,t} \) units of skilled labor used can produce \( Z_{N,t} \) new innovations.\textsuperscript{9} As described in the previous subsection, the new innovations introduced at time \( t \) add to the total stock of potential technologies already existing. Innovations sell at price \( J_t \). Note that, as in Romer (1990), (36) incorporates an externality of the aggregate technological level, \( A_t \), on the efficiency of skilled labor in introducing new innovations. As Romer (1990) shows, this assumption is key to generate endogenous growth.

For simplicity, I assume that the aggregate supply of skilled labor is inelastic and fixed at \( \bar{L}_S \). This assumption, together with perfect competition in producing innovations, can be shown to generate a positively sloped supply curve of new innovations, given by:

\[ J_t = \frac{1}{\eta} \left( \frac{1}{L_S} \right)^{\frac{1-\eta}{\eta}} \left( \frac{Z_{N,t}}{A_t} \right)^{\frac{1-\eta}{\eta}} \]

The amount of final output used by the innovation sector is given by:

\[ N_t = \eta Z_{N,t} J_t \]

\section*{3.4 Final Output and Intermediates Producers}

The final good is produced in a competitive sector which aggregates a continuum of measure \( A_t \) of intermediates:

\textsuperscript{8}See Levine (1997, 2005) for surveys of evidence suggesting that financial development has a positive impact on long-run TFP and output growth.

\textsuperscript{9}This formulation is common in models of technology innovation and adoption - see for example Santacreu (2010) and references therein. In particular, it captures the spirit of the Nelson-Phelps hypothesis that the stock of skilled labor affects the rate of arrival of potential technologies - see Nelson and Phelps (1966) and Benhabib and Spiegel (1994).
\[ Y_t = \left[ \int_0^{A_t} Y_t(s) \frac{\vartheta - 1}{\vartheta} ds \right]^{\vartheta} \] \hspace{1cm} (37)

Given the aggregator above, demand for each intermediate \( s \) is

\[ Y_t(s) = \left[ \frac{P_t(s)}{P_t} \right]^{-\vartheta} Y_t \] \hspace{1cm} (38)

where the price level \( P_t \) is defined as

\[ P_t = \left[ \int_0^{A_t} P_t(s)^{1-\vartheta} ds \right]^{\frac{1}{1-\vartheta}} \] \hspace{1cm} (39)

Equation (38) gives the demand facing each intermediate good producer \( s \). Intermediates are produced using a standard Cobb-Douglas technology with capital services \( u_t(s)K_t(s) \) and labor \( L_t(s) \) as inputs:

\[ Y_t(s) = [u_t(s)K_t(s)]^\alpha L_t(s)^{1-\alpha} \] \hspace{1cm} (40)

Intermediate goods firms face a working capital requirement which forces them to hold an amount of non-interest-bearing assets that is no smaller than a multiple \( \theta_W \) of the quarterly wage bill:

\[ \kappa_t(s) \geq \theta_W W_t L_t(s) \hspace{1cm} \theta_W \geq 0 \]

where \( \kappa_t(s) \) denotes the amount of working capital held by firm \( s \) in period \( t \). As shown in Uribe and Yue (2006) and Mendoza and Yue (2011), this formulation implies that the effective cost of labor becomes \( [1 + \theta_W \left( \frac{R_t - 1}{R_t} \right)] W_t \), and therefore an increase in the interest rate reduces the demand of labor by intermediates firms.

The objective of intermediates producers is to maximize profits, including the value of the remaining part of capital they rent from households. Firms face a replacement price of depreciated capital equal to unity.\(^{10} \) Thus, their objective is to solve

\[
\max_{P_t(s), Y_t(s), u_t(s), K_t(s), L_t(s)} P_t(s)Y_t(s) + P_{K,t}K_t(s) - \delta(u_t(s))K_t(s) - \left[ 1 + \theta_W \left( \frac{R_t - 1}{R_t} \right) \right] W_t L_t(s) - R^K_t K_t(s)
\]

\(^{10}\) As made clear below, adjustment costs are on net rather than gross investment, so that replacing worn-out capital does not involve adjustment costs. This formulation makes the capital utilization decision independent of the price of capital.
Subject to (38) and (40). Solving the firm’s problem yields the following equations:

\[ 1 + \theta W \left( \frac{R_t - 1}{R_t} \right) \] \( W_t = (1 - \alpha) \frac{Y_t}{L_t} \) (41)

\[ R_t^k = \alpha \frac{Y_t}{K_t} + P_{K,t} - \delta(u_t) \] (42)

\[ \frac{\alpha Y_t}{u_t} = \delta'(u_t) K_t \] (43)

Per period profits \( \pi_t \) can be shown to be equal to

\[ \pi_t = \frac{1}{\vartheta} \frac{Y_t}{A_t} \] (44)

It then follows that the price of an adopted technology, \( v_t \), corresponds to the expected present value of profits received by the monopolists from marketing the specialized intermediate good:

\[ v_t = \mathbb{E}_t \left[ \sum_{i=0}^{\infty} \zeta_i A_{t,t+i} \pi_{t+i} \right] \] (45)

Above, (45) incorporates the effect of obsolescence, through parameter \( \zeta \). Finally, combining the aggregator (37) with the equations for intermediates producers one obtains an expression for final output:

\[ Y_t = A_t^{\frac{1}{\alpha}} (u_t K_t)^\alpha L_t^{1-\alpha} \] (46)

### 3.5 Capital Producers

At the end of period \( t \), capital producing firms repair depreciated capital and produce new capital. As in and Gertler et. al. (2007), repair of old capital is not subject to adjustment costs, but there are stock adjustment costs associated with the production of new capital. Let \( I^n_t \) be net investment, the amount of investment used for construction of new capital goods:

\[ I^n_t = I_t - \delta(u_t) K_t \] (47)

To produce new capital, capital producers combine final output with existing capital via the constant returns to scale technology \( \Phi(I^n_t / K_t) K_t \), where \( \Phi(\cdot) \) is increasing and concave and satisfies \( \Phi(I^n_t / K) = 0 \) and \( \Phi'(I^n_t / K) = 1 \), where \( I^n_t / K \) is the net investment to capital
ratio along the balanced growth path.

The economy-wide capital stock evolves according to \(^\text{11}\)

\[
K_{t+1} = K_t + \Phi \left( \frac{I^n_t}{K_t} \right) K_t
\]  

(48)

As in Gertler et. al. (2007), I assume that capital producing firms make production plans one period in advance, with the objective of capturing the delayed response of investment observed in the data. Accordingly, the optimality condition for capital producers is

\[
\mathbb{E}_{t-1}(P_{K,t}) = \mathbb{E}_{t-1} \left\{ \left[ \Phi' \left( \frac{I^n_t}{K_t} \right) \right]^{-1} \right\}
\]  

(49)

3.6 Market Clearing

The economy uses output and international borrowing to finance consumption, investment in physical capital, and investment in new technology. The resulting market clearing condition is

\[
\frac{1}{R_t} B_t - B_{t-1} + Y_t = C_t + I_t + N_t
\]  

(50)

\(B_t\) is economywide foreign indebtedness, equal to the sum of aggregate family and entrepreneurial debt \((B_t = D^F_t + D_t)\). Equation (50) can be derived by combining family and entrepreneur budget constraints with equilibrium conditions.

The description of the model is now complete.

4 Model Analysis

In this section I present some numerical experiments from a calibrated version of the model. The goal is to illustrate how the novel mechanism introduced in the paper, namely financially constrained technology adoption, may lead to the persistent declines in productivity, employment and output following financial crises that we observe in the data. The first set of results concerns the response of the model economy to a “crisis” experiment. The aim is to illustrate how a sudden stop in capital inflows may lead to a medium run productivity decline as observed in the data, and how the financial market imperfection may work to amplify the decline. It is also shown how employment and output may suffer persistent drops as a consequence.

\(^{11}\)Given the assumptions on \(\Phi(\cdot)\), to a first order the evolution of capital along the balanced growth path is the usual \(K_{t+1} = [1 - \delta(u_t)] K_t + I_t\).
I next examine the consequences of a reduction in the “efficiency” of financial markets, captured in the model by a reduction in the amount lenders are able to recover from entrepreneurs in the event of a default, occurring simultaneously with the country interest rate shock. The aim is to capture a situation like the one in East Asia 1996-97, in which domestic financial market disruptions accompanied the outflow of capital.

Finally, I also examine the response of the model to two types of non-financial shocks. In particular, I analyze the effects of exogenous TFP shocks and wage markup shocks.

4.1 Parameter Values

There are a total of nineteen parameters in the model, of which twelve are standard in the emerging markets business cycles literature. Of the remaining seven, four relate to the endogenous growth process: the adoption probability ($\lambda$), the rate of obsolescence ($1 - \zeta$), the share of materials used in the innovation sector ($\eta$) and the supply of skilled labor ($L_S$). The remaining three parameters relate to the financial market imperfection. They include the survival rate of entrepreneurs ($\sigma$), the divertable fraction of assets ($\theta$), and the transfer rate to new entrepreneurs ($\xi$).

I choose relatively conventional values for the standard parameters. The discount factor is set at 0.99, and risk aversion is set at unity. I set the inverse Frisch elasticity of labor supply, $\epsilon$, equal to one. I set the habits parameter $h$ at 0.2, similar to the value estimated by Uribe and Yue (2006). The parameter $\gamma$ governing the impact of the aggregate technological level $A_t$ on the labor disutility term $\Gamma_t$ is set at 0.01, implying that aggregate technology impacts the disutility of work only over the very long run. Turning to technology parameters, I set the capital share $\alpha$ to $1/3$, and the quarterly depreciation rate of physical capital, $\delta$, to 2.5%. Capital utilization along the balanced growth path is normalized to 1, and the elasticity of marginal depreciation with respect to the utilization rate ($\delta''/\delta'$), is set at 0.15, as in Jaimovich and Rebelo (2009) and Comin, Gertler and Santacreu (2009). I set the elasticity of the price of capital with respect to the investment-capital ratio at 0.25, as in Gertler et. al. (2007) and Bernanke et. al. (1999). I choose the parameter on the intermediate goods aggregator, $\vartheta$, so that output is proportional to TFP along the balanced growth path, which by looking at equation (46) amounts to imposing $(1 - \alpha)(\vartheta - 1) = 1$. This restriction makes profits per period, $\pi_t$, a stationary variable, and simplifies somewhat the characterization of the balanced growth path. Given $\alpha = 1/3$, the resulting value for the markup is $\vartheta/(\vartheta - 1) = 1.66$, close to the value of 1.6 chosen by Comin and Gertler (2006).

Regarding the working capital constraint, I set $\theta_W = 0.25$, implying that firms need to
pay less than a month’s worth of the wage bill in advance. The debt to GDP ratio along
the balanced growth path is set at 0.2, and the elasticity of the interest rate with respect to
the debt-output ratio equals 0.0001 – the latter ensures that the dynamics of the model are
virtually unaffected by the debt-elastic interest rate at high and medium frequencies, while
still making the foreign asset position revert to trend over the long run.

Turning to the parameters governing the TFP growth process, I choose the supply of
skilled labor, $\bar{L}_S$, to generate an annual TFP growth of 3.0%, similar to the average in
East Asia post-1980. I set the adoption probability $\lambda$ to obtain an average diffusion lag of
3 years, a value in the high end of the estimates in Pakes and Schankerman (1984). Also
following Pakes and Schankerman (1984) I set $\zeta$ to deliver an annual obsolescence rate of 10%.
Finally, based on the presumption that technology production is relatively labor-intensive, I
set $\eta = 0.125$, which implies that along the balanced growth path 10% of output is used by
the innovation sector.

The choice of the financial sector parameters is meant to be suggestive. I set the entre-
preneur survival rate $\sigma = 0.98$, implying an expected horizon of entrepreneurs of about
12 years. To calibrate the fraction of resources that entrepreneurs can divert, $\theta$, and the
transfer to new entrants, $\xi$, I target two features of the balanced growth path of the model
economy: a leverage ratio (assets to equity) of four, and an excess return $E(R_Z - R$ equal
to one hundred basis points annually. The target for the leverage ratio is guided by the
evidence on debt to equity ratios for South Korean chaebols and manufacturing firms prior
to the 1997 crisis, as reported by Krueger and Yoo (2001). These authors document that
these firms were highly leveraged in 1997: the debt-equity ratio was 5.2 for the thirty largest
chaebols, 4.8 for the five largest chaebols, 4.6 for the five largest manufacturing firms and
3.9 for all firms in the manufacturing sector. Thus, an assets-equity ratio of four is relatively
conservative. On the other hand, average debt-equity ratios in the period 1985-1998 are
somewhat lower – around 3.5 for the five largest manufacturing firms, and about 3 for all
manufacturing firms, similar to my chosen value. On the other hand, Gertler et. al. (2007)
document that spreads between corporate and government bonds in Korea appeared to be
consistently zero prior to 1997, which they interpret as evidence of government guarantees
to the Korean corporate sector. For this reason, I instead target an annual spread of a
percentage point, following evidence on spreads between corporate and government bonds
in the U.S. . These targets imply setting the divertable fraction $\theta$ at 0.45, and the transfer
rate $\xi$ at 0.01.

---

12While higher values of this parameter are frequently used in the literature, Mendoza and Yue (2011)
argue that it is desirable to set this parameter at a relatively low value, since empirical estimates suggest
that working capital is a small fraction of GDP. A working capital requirement of 0.25, together with a wage
bill of two thirds of GDP, implies a ratio of working capital to GDP of around 16%.
Table 1 reports the values chosen for the model parameters together with a reminder of their meaning.

4.2 Crisis Experiment (1): Interest Rate Shock

In this subsection, I analyze the effects of an unanticipated increase in the country interest rate. In particular, I consider a 750 basis point increase in $r_t$ that persists as a first-order autoregressive process with a 0.88 coefficient. These magnitudes are close to the evidence for the crisis in South Korea in 1997, as shown by Gertler et. al. (2007). More generally, large country interest rate fluctuations are thought to be an important driver of emerging markets business cycles – see for example Neumeyer and Perri (2005) or Uribe and Yue (2006).

Figure 5 documents the effect of the interest rate shock on the financial side of the model. The disturbance induces a large decline in the prices of adopted and unadopted technologies, as the stream of future profits per adopted intermediate good is discounted more heavily. This has the effect of generating a large drop in aggregate entrepreneurial net worth, as equation (30) indicates. Notice that the value of unadopted technologies, $J_t$, falls substantially more than in the frictionless benchmark: as entrepreneurs’ constraints tighten (as reflected in the increase in the multiplier on the incentive constraint), they are forced to cut back on project funding to a larger extent than what would happen with frictionless financial markets. Along the way, there is “adverse feedback” between net worth and the franchise value $J_t$: as the former falls, entrepreneurs’ constraints tighten, forcing a decline in the credit available for projects in development. The decrease in demand for new projects leads to further reductions in their franchise value $J_t$.

The tightening of financial constraints is also reflected in the rise in excess returns $E_t(R_{Z,t+1}) - R_t$, which reflects that profitable opportunities of investment in technology adoption projects go unexploited due to an intensification of financial market frictions. The rise in the spread represents a widening of the departure from perfect arbitrage, as exemplified by equation (35). The flow of credit to entrepreneurs is reduced substantially as a consequence of the shock, as the first panel in the last row indicates. Finally, the aggregate amount of new projects, $Z_{N,t}$, falls substantially more in the model with frictions compared to the frictionless model, and the drop is considerably more persistent.

The decline in the number of projects funded by the entrepreneurial sector directly translates into a decline in the rate of new adoptions. As Figure 6 shows, it follows that there is a substantial slowdown in the growth rate of TFP, leading to a permanent drop in the level of this variable relative to its unshocked path. Further, the magnitude of the medium-run decline is substantially larger due to financial factors – on the order of 50 percent larger.
relative to the frictionless model. Thus, the financial friction plays a quantitatively signif-
ican role in helping the model generate a realistic behavior of TFP following a crisis, as
illustrated for example in the case of South Korea reviewed earlier, in which TFP remained
persistently depressed relative to trend by about 6%.

Figure 7 summarizes the key results regarding the effect of the interest rate shock, by
plotting the model counterpart of the empirical impulse responses documented in Section 2:
it displays the behavior of output, labor productivity and employment following the shock,
relative to the unshocked path of the economy. In the case of a frictional financial market,
there is a large permanent component to the decline in output, which is substantially larger
than in the frictionless benchmark – about 2 percentage points larger, 50 percent more than
without frictions. Behind the results in Figure 7 is the behavior of technology adoption
following the crisis, and its impact on aggregate TFP. This is the main driving force behind
the behavior of labor productivity displayed in the figure. At the same time, as shown
in the last panel of Figure 7, the permanent decline in productivity leads to a decline in
labor demand by producers of intermediates. As a result, employment also falls persistently
relative to the unshocked path of the economy, with an important portion of the decline
being due to financial frictions. Thus, the model is also able to account for the evidence
provided in Section 2 that employment remains persistently depressed following financial
crises. The financial friction helps generate a realistic magnitude of the employment drop:
in the data it is about 4 percent after four years, while in the model with and without
financial frictions it is 3 and 2 percent, respectively. Overall, the bottomline from Figure 7
is that the mechanisms introduced in the model appear to have potential for quantitatively
accounting for the behavior of output, labor productivity and employment following financial
crises.

Finally, Figure 8 plots the response of a set of standard macroeconomic variables. Overall,
the model does a relatively good job of capturing quantitatively the macroeconomic effects
of the typical emerging markets financial crisis. In particular, the responses of the variables
displayed in Figure 11 are reasonably close to the evidence for the Korean 1997 crisis, as
documented for example in Gertler et. al. (2007), especially regarding the magnitude of the
decline in investment and the large reversal in the net exports to GDP ratio. As discussed
above, the mechanisms introduced in this paper help in accounting for the persistence in
the output decline following these episodes. A final point to highlight from Figure 11 is the
substantial amplification due to the financial friction of aggregate consumption, a variable
which is well known to display higher volatility relative to GDP in emerging markets when
compared to more developed economies, and also of the ratio of net exports to GDP.
4.3 Crisis Experiment (2): Tightening Margins

In the preceding subsection, a financial crisis was triggered by an unanticipated increase in the country interest rate. This was meant to capture the sudden outflow of capital that has often afflicted emerging market economies in recent times. A complementary way in which financial distress can transmit to the real economy is by a tightening of entrepreneurs’ leverage ratio, arising from an intensification of agency problems in financial markets. In particular, suppose that the fraction of assets that lenders can recover, $\theta$, might vary. An increase in $\theta_t$ is interpretable as a reduction in the efficiency of financial markets, as lenders are able to recover a smaller amount from defaulting borrowers.\(^{13}\)

With a time-varying $\theta_t$, equation (29) now becomes

$$J_t S_t = \frac{\nu_t}{\theta_t - \mu_t} W_t$$

(51)

Clearly, an increase in $\theta_t$ will reduce the aggregate amount of projects funded by entrepreneurs: as the incentive constraint tightens, lenders are willing to extend less credit per unit of net worth.

Figure 9 illustrates the implications of an increase in $\theta_t$ occurring simultaneously with the interest rate shock. Specifically, $\theta_t$ rises to 0.75 from its steady state value of 0.45, and the increase persists as a first order autoregressive process with coefficient 0.95. As a result, the slowdown in the rate of introduction of new products is substantially more severe. It follows that the magnitude of the medium-run decline in productivity, employment and output is considerably greater, and closer to the empirical magnitudes reported in Section 2.

4.4 Non-financial Shocks

In this subsection, I analyze the behavior of the model economy following two types of non-financial shocks that have been highlighted in the literature as important sources of business cycle fluctuations: an exogenous TFP shock, and a wage markup shock. To introduce the former, I modify the production function of intermediate goods firms as follows:

$$Y_t(s) = \bar{A}_t [u_t(s)K_t(s)]^\alpha L_t(s)^{1-\alpha}$$

(52)

Above, $\bar{A}_t$ is an exogenous aggregate TFP shock. To introduce the wage markup shock, the labor supply equation is modified according to the following:

---

\(^{13}\)Kiyotaki and Moore (2008), Del Negro, Eggertsson, Ferrero and Kiyotaki (2010) and Jermann and Quadrini (2009) use a mechanism in this spirit to motivate a disruption in financial markets.
\[ W_t = \mu_t^W \frac{\Gamma_t L_t^e}{U_{C,t}} \]  

\( \mu_t^W \) is a markup of the wage over the household’s marginal disutility of work. Several authors have argued that countercyclical movements in the wage markup are an important source of business fluctuations,\(^{14}\) possibly by capturing in a reduced-form way the effects of nominal price and wage rigidities or labor market frictions.

Figures 10 and 11 report the effects of a 5% decline in exogenous TFP and a 5% increase in the wage markup, respectively. Both shocks persist as an AR(1) with a 0.95 coefficient. The key point to note is that both shocks induce only modest declines in the endogenous component of TFP, and that the degree of amplification through the credit market imperfection is also relatively small. The reason is that unlike financial shocks, these two types of shocks induce modest movements in the prices of adopted and unadopted technologies, \( v_t \) and \( J_t \). As a consequence, their adverse impact on the financial constraints of technology adopters is relatively small. As the figures show, it follows that these types of disturbances are followed by a recovery, which is driven by the unwinding of the shock. Thus, the bottomline from Figures 10 and 11 is that the model is also consistent with the evidence that slow recoveries are a phenomenon especially associated with financial crises, as Reinhart and Rogoff (2009) and others have noted.

5 Concluding Remarks

This paper has sought to explain the phenomenon of slow recoveries following financial crises. It has argued that the large and persistent productivity and TFP declines observed during banking crises in emerging economies can be a natural consequence of an adverse shock in an environment in which productivity growth is endogenous through the adoption of new technologies. Further, it has shown how domestic financial market disruptions can work to amplify these declines. The model is able to deliver the persistent declines in output, labor productivity and employment following financial crises in a manner that is quantitatively consistent with the evidence. The model is also shown to generate reasonable behavior of macroeconomic aggregates, with the financial friction delivering substantial amplification of consumption and the current account. Finally, the model predicts that the lack of recovery is more severe following financial shocks than following nonfinancial shocks, also consistent with what we observe in the data.

While the evidence motivating the model introduced in this paper has been based on

the experience of emerging market economies – after all, it is in these countries that most financial crises have occurred over the past decades – the recent experience in the U.S. and Europe in the aftermath of the Great Recession suggests that the mechanism identified in this paper may be relevant to industrialized countries as well.

A potentially interesting application of the framework presented in this paper would be an evaluation of the welfare gains of government intervention in mitigating a financial crisis. Gertler and Karadi (2009) and Gertler, Kiyotaki and Queralto (2011), for example, analyze different government financial policies in the context of the recent financial crisis in the US, finding important benefits of government intervention. The endogenous productivity growth mechanism introduced in this paper would likely affect what is at stake when considering intervention during a financial meltown, and therefore it could have a substantial impact on the welfare gains of government policies directed at ameliorating the impact of a financial crisis.
6 Appendix

A Data

Financial crises. Banking crisis dates are obtained from Caprio and Klingebiel (2003). I obtain output and employment data from the Total Economy Database\textsuperscript{15}, maintained by the Conference Board and the Groningen Growth and Development Centre, which contains yearly series for 90 countries for the period 1950-2009. The list of emerging countries used in the analysis is the following: Argentina, Brazil, Chile, China, Colombia, Hong Kong, Hungary, India, Indonesia, South Korea, Malaysia, Mexico, Peru, Philippines, Poland, Singapore, Thailand, Turkey and Vietnam.

B The Complete Model

B.1 Conventional Part

Production function:

\[ Y_t = A_t^{\frac{1}{1-\alpha}} (u_tK_t)^{\alpha} L_t^{1-\alpha} \]  \hspace{1cm} (54)

Marginal utility of consumption:

\[ U_{C,t} = u_{C,t} - \beta h E_t (u_{C,t+1}) \]  \hspace{1cm} (55)

\[ u_{C,t} = \left( C_t - hC_{t-1} - \Gamma_t \frac{1}{1+\epsilon} L_{t+t} \right)^{-\rho} \]  \hspace{1cm} (56)

Labor market equilibrium:

\[ \frac{u_{C,t} \Gamma_t L_t}{U_{C,t}} = \frac{1}{1 + \theta W (\frac{R_t-1}{R_t})} (1 - \alpha) \frac{Y_t}{L_t} \]  \hspace{1cm} (57)

Stochastic discount factor:

\[ \Lambda_{t,t+1} = \frac{\beta U_{C,t+1}}{U_{C,t}} \]  \hspace{1cm} (58)

International bond Euler Equation:

\textsuperscript{15}http://www.conference-board.org/economics/database.cfm
1 = \mathbb{E}_t (\Lambda_{t,t+1}) R_t \tag{59}

Capital Euler Equation (demand for capital):

1 = \beta \mathbb{E}_t \left( \Lambda_{t,t+1} \frac{\alpha Y_{t+1} + P_{K,t+1} - \delta(u_{t+1})}{P_{K,t}} \right) \tag{60}

Supply of capital:

\mathbb{E}_{t-1}(P_{K,t}) = \mathbb{E}_{t-1} \left\{ \left[ \Phi' \left( \frac{I^n_t}{K_t} \right) \right]^{-1} \right\} \tag{61}

Net investment:

I^n_t = I_t - \delta(u_t)K_t \tag{62}

Capital accumulation:

K_{t+1} = K_t + \Phi \left( \frac{I^n_t}{K_t} \right) K_t \tag{63}

Optimal utilization:

\frac{\alpha Y_t}{u_t} = \delta'(u_t)K_t \tag{64}

Market clearing:

\frac{1}{R_t} B_t - B_{t-1} + Y_t = C_t + I_t + N_t \tag{65}

International bond price:

R_t = r + \epsilon r + \psi \left[ e^{\frac{B_t - B_{t-1}}{R_t}} - 1 \right] \tag{66}

\section*{B.2 Endogenous Growth and Financial Frictions Part}

Profits per intermediate good:

\pi_t = \frac{1}{\vartheta} Y_t \tag{67}

Value of a new intermediate good:
\[ v_t = \pi_t + \zeta \mathbb{E}_t(A_{t,t+1}v_{t+1}) \]  \hspace{1cm} (68)

Evolution of aggregate net worth:

\[ W_t = \sigma [(R_{Z,t} - R_{t-1}) + R_{t-1}W_{t-1}] J_{t-1}S_{t-1} + (1 - \sigma)\xi_{t-1}S_{t-1} \]  \hspace{1cm} (69)

Constraint on technology adoption:

\[ J_t [\zeta Z_t + Z_{N,t} - A_t] = \phi_t W_t \]  \hspace{1cm} (70)

Value function coefficients:

\[ \Omega_{t+1} = 1 - \sigma + \sigma (\mu_t + \phi_t \mu_t) \]  \hspace{1cm} (71)

\[ \mu_t = \mathbb{E}_t [A_{t,t+1}\Omega_{t+1} (R_{Z,t+1} - R_t)] \]  \hspace{1cm} (72)

\[ \nu_t = \mathbb{E}_t (A_{t,t+1}\Omega_{t+1}) R_t \]  \hspace{1cm} (73)

Evolution of adopted and unadopted technologies:

\[ A_{t+1} = \lambda [\zeta Z_t + Z_{N,t} - A_t] + \zeta A_t \]  \hspace{1cm} (74)

\[ Z_{t+1} = \zeta Z_t + Z_{N,t} \]  \hspace{1cm} (75)

Price of innovations:

\[ J_t = \frac{1}{\eta} \left( \frac{1}{L_S} \right)^{\frac{1-n}{n}} \left( \frac{Z_{N,t}}{A_t} \right)^{\frac{1-n}{n}} \]  \hspace{1cm} (76)

Materials used in innovation sector:

\[ N_t = \eta Z_{N,t} J_t \]  \hspace{1cm} (77)

In the frictionless benchmark, the following equation holds:

\[ J_t = \mathbb{E}_t \{A_{t,t+1} [\lambda v_{t+1} + (1 - \lambda)\zeta J_{t+1}]\} \]  \hspace{1cm} (78)

The model is solved by first appropriately detrending the variables that exhibit long-run
growth. With the redefined “detrended” variables, a stationary system obtains. The steady state of that system characterizes the balanced growth path of the economy. Dynamics are obtained by computing a loglinear approximation around the balanced growth path.
References


**Table 1: Calibration**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.99</td>
<td>Discount factor</td>
</tr>
<tr>
<td>$\rho$</td>
<td>1</td>
<td>Risk aversion</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>1</td>
<td>Inverse Frisch elasticity</td>
</tr>
<tr>
<td>$h$</td>
<td>0.20</td>
<td>Habits</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.01</td>
<td>Parameter on labor disutility term</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.025</td>
<td>Capital depreciation</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>1/3</td>
<td>Capital share</td>
</tr>
<tr>
<td>$\delta''/\delta'$</td>
<td>0.15</td>
<td>Elasticity of depreciation to utilization</td>
</tr>
<tr>
<td>$\vartheta$</td>
<td>2.5</td>
<td>Demand elasticity for intermediates</td>
</tr>
<tr>
<td>$\Phi''(I^n/K)$</td>
<td>0.25</td>
<td>Elasticity of $P_k$ to $I^n/K$</td>
</tr>
<tr>
<td>$\theta_W$</td>
<td>0.25</td>
<td>Working capital requirement</td>
</tr>
<tr>
<td>$\psi$</td>
<td>0.0001</td>
<td>Elasticity of interest rate to foreign debt</td>
</tr>
<tr>
<td>$B/Y$</td>
<td>0.2</td>
<td>Foreign debt to output</td>
</tr>
<tr>
<td><strong>Growth</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.08</td>
<td>Probability of adoption</td>
</tr>
<tr>
<td>$1 - \zeta$</td>
<td>0.025</td>
<td>Obsolescence rate</td>
</tr>
<tr>
<td>$\eta$</td>
<td>0.125</td>
<td>Final output share in innov.</td>
</tr>
<tr>
<td>$\ell_S$</td>
<td>0.4725</td>
<td>Skilled labor supply</td>
</tr>
<tr>
<td><strong>Financial Frictions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma$</td>
<td>0.98</td>
<td>Survival rate</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.45</td>
<td>Fraction divertable</td>
</tr>
<tr>
<td>$\xi$</td>
<td>0.01</td>
<td>Transfer rate</td>
</tr>
</tbody>
</table>
Figure 1: Total output, employment and output per employed worker (logs) for group of 6 South East Asian countries (Indonesia, Malaysia, Philippines, Korea, Thailand and Hong Kong).
Figure 2: Labor productivity (log) for group of 6 South East Asian countries (Indonesia, Malaysia, Phillipines, Korea, Thailand and Hong Kong).
Figure 3: Estimated impulse responses to a banking crisis. Time measured in years.
Figure 4: TFP, patents and trademarks, South Korea.
Figure 5: Impulse responses to interest rate shock, endogenous growth and financial frictions variables. Time measured in years.
Figure 6: Impulse responses to interest rate shock, TFP growth rate and TFP. Time measured in years.
Figure 7: Responses of output, labor productivity and employment to interest rate shock.
Figure 8: Impulse responses to interest rate shock, macroeconomic variables. Time measured in years.
Figure 9: Responses of output, labor productivity and employment, tightening margins together with interest rate shock.
Figure 10: Responses of net worth, spread, TFP, output, labor productivity and employment to exogenous TFP shock.
Figure 11: Responses of net worth, spread, TFP, output, labor productivity and employment to wage markup shock.