A Quantitative Model of Slow Recoveries from Financial Crises*

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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 TFP growth through the adoption of new varieties of intermediates, and an agency problem in financial markets which implies that technology adopters may be credit constrained. A crisis shock generates a decline in TFP of size and persistence comparable to the data. Financial frictions are quantitatively important, explaining half the medium run TFP decline. Both endogenous growth and the financial friction substantially contribute to a more persistent output decline and to an amplified short run response of consumption. These mechanisms also help in accounting for the time series properties of Argentina's GDP and Solow residual, especially at medium frequencies.

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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 episodes tend to be strikingly similar in many respects, one of which is 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 a large 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 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 is endogenous through the adoption of new technologies. I use a formulation similar to Romer (1990), whereby endogenous growth results from the introduction 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 the assets he controls. 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. The former feature is introduced to illustrate the relative importance for productivity dynamics at different frequencies of variable input utilization versus the novel mechanism in the paper, namely endogenous TFP growth. Consumption habits and working capital help produce a more realistic short-run behavior of consumption and hours in response to a crisis shock.

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 prices of assets controlled by entrepreneurs, increases the severity of the agency problem between entrepreneurs and their creditors, making the assets owned by the former less collateralizable and constraining the flow of credit to entrepreneurs. The result at the macroeconomic level is a substantial reduction of the pace at which the entrepreneurial sector introduces new varieties of intermediates, leading TFP to drop permanently as a result. Financial factors contribute substantially to the TFP decline: for the baseline calibration presented below, the shock generates a permenent TFP decline of almost 6%, half of which is due to financial factors. Both endogenous growth and the financial friction contribute substantially to a more persistent output decline due to the crisis, and they also amplify considerably the movements in consumption in the short and medium run.

In a second experiment, I evaluate the ability of the model to generate fluctuations with statistical properties similar to those of Argentine data for the period 1950-2005. Over this period, Argentina's GDP has displayed large and persistent fluctuations at medium frequencies, largely accounted for by movements in the Solow residual. I show that the novel mechanisms introduced in this paper contribute substantially to an improved model performance in that respect.

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) or Kehoe and Ruhl (2009). 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.

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 heterogeneus 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 finacial 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, Phillipines, 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 permanently below the pre-crisis trend.[2] Looking at the second and third panels, the behavior

[1]See Griliches (1990) and Jaffe and Trajtenberg (2002) for discussions on patents as indicators of technological change, and Yorukolgu (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.

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:

$$log(Y_t) = log(\frac{Y_t}{L_t}) + log(L_t) = yl_t + l_t$$

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

$$\mathbf{x}_{i,t} = a_i + \sum_{j=1}^{4} A_j \mathbf{x}_{i,t-j} + \sum_{s=0}^{4} B_s D_{i,t-s} + \epsilon_{i,t} \tag{1}$$

where

$$\mathbf{x}_{i,t} = \begin{bmatrix} \Delta yl_{i,t} \\ \Delta n_{i,t} \end{bmatrix}$$

$D_{i,t}$ 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

[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%.

[4]See appendix A for a list of the countries used in the analysis and details on the data.

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 some 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 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.

[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.

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 macroeconomic 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 $(1-\theta)$. 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 $(1-\theta)\frac{f}{1-f}$ 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

$$u(C_t, L_t) = \frac{1}{1-\sigma}\left[(C_t - \gamma C_{t-1})^{1-\xi}(1-\mu_t^W L_t)^{\xi}\right]^{1-\sigma} \tag{2}$$

μ_t^W is a shock to the disutility of labor that acts as a labor supply shifter. It is assumed to fluctuate around unity as a first-order autoregressive process. 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:

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

subject to

$$C_t + P_{K,t}K_{t+1} \leq R_t^k K_t + W_t L_t + \frac{1}{R_t} D_t^F - D_{t-1}^F + \tau_t$$

Above, $P_{K,t}$ is the price of capital and R_t^k is its rental rate, W_t the wage rate and R_t is the interest rate on the international bond. D_t^F denotes the family's choice of foreign debt and K_{t+1} is the choice for physical capital holdings. Finally, τ_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:

$$R_t = r + e^{r_t} + \psi \left[e^{\frac{B_t - B}{Y_t}} - 1 \right] \tag{3}$$

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 ψ so that this feature does not affect the dyamics 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:

$$U_{C,t} = u_{C,t} - \beta\gamma \mathbb{E}_t \left(u_{C,t+1} \right) \tag{4}$$

$$u_{C,t} = (1-\xi)(C_t - \gamma C_{t-1})^{-[(1-\xi)\sigma+\xi]}(1-\mu_t^W L_t)^{\xi(1-\sigma)} \tag{5}$$

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

$$\Lambda_{t,t+i} \equiv \frac{\beta U_{C,t+i}}{U_{C,t}} \tag{6}$$

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

$$1 = \mathbb{E}_t \left(\Lambda_{t,t+1} \right) R_t \tag{7}$$

$$1 = \mathbb{E}_t \left(\Lambda_{t,t+1} \frac{R_{t+1}^k}{P_{K,t}} \right) \tag{8}$$

Labor supply is given by

$$\frac{\xi \left(C_t - \gamma C_{t-1} \right)^{(1-\xi)(1-\sigma)} \left(1 - \mu_t^W L_t \right)^{\xi(1-\sigma)-1}}{U_{C,t}} = W_t \tag{9}$$

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. 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 λ each period. Both adopted and unadopted projects are subject to the risk of (exogenously) becoming obsolete: $(1-\phi_A)$ and $(1-\phi_Z)$ represent the respective obsolescense probabilities. When an entrepreneur is successful in one of his projects, he receives the exclusive right to rent that new design to a producer of intermediates, which manufactures it and sells it to final goods producers. This reports a cash flow of π_t to the entrepreneur. In the description of intermediates producers below I show how π_t is determined. Thus the value of an adopted technology, denoted by v_t, is the present discounted value of the profit flow it gives right to, where future uncertain profits are weighted by the household's stochastic discount factor $\Lambda_{t,t+i}$, and by the probability that the technology does not become obsolete ϕ_A^i:

$$v_t = \mathbb{E}_t \left[\sum_{i=0}^{\infty} \phi_A^i \Lambda_{t,t+i} \pi_{t+i} \right] \tag{10}$$

The financial market imperfection takes the form of a limited enforcement problem between the entrepreneur and his creditors: after making the decision on how much to borrow and invest in purchases of innovations, an entrepreneur can default on his debt and liquidate a fraction of the assets he controls, with lenders only being able to recover the remaining part. 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. I refer to Figure 6 for a description of the period-t timing protocol for an individual entrepreneur. Let a_t be the number of adopted technologies an entrepreneur controls at the beginning of period t, z_t the number of unadopted technologies, and d_{t-1} his debt. The triplet (a_t, z_t, d_{t-1}) is the entrepreneur's individual state in the beginning of period t. His beginning-of-period value is $V_t(a_t, z_t, d_{t-1})$, where the subindex t on the value function reflects aggregate uncertainty. Once aggregate uncertainty is realized, the entrepreneur chooses how much to borrow, d_t, and how many new innovations to purchase, $z_{N,t}$. The market for innovations is competitive and an innovation has price J_t. The choice of d_t and $z_{N,t}$ is subject to a budget constraint and a no-default constraint. The entrepreneur then finds out whether he has to exit at the end of the period, which happens with probability $(1-\theta)$, or if he stays as an entrepreneur. In the former case, he transfers his net earnings to the household, which consist of the value of the assets he controls (including the technologies he has managed to adopt during period t) net of his debt d_t. In the case he does not die, he can default on his debt and divert the liquidated value of a certain fraction of the assets he controls, which he then transfers to the household. Default takes place at the end of the period, once the outcome of the entrepreneur's projects in period t is already known, but before the realization of aggregate uncertainty in period $t+1$. I assume the entrepreneur can divert fraction ψ_A of the value of his adopted technologies and fraction ψ_Z of the value his unadopted technologies, with $\psi_A, \psi_Z < 1$. Thus the total payoff to an entrepreneur if he defaults is $\psi_A(v_t - \pi_t)\mathbb{E}_t(a_{t+1}) + \psi_Z J_t \mathbb{E}_t(z_{t+1})$. If he does not default, he goes into period $t+1$. Therefore, the no-default constraint which the entrepreneur faces when choosing debt d_t requires that the continuation value be greater than the default payoff. The objective of an entrepreneur is to choose a state-contingent sequence $(z_{N,i}, d_i)$ to maximize the expected present value of the terminal payout to the household:

$$\mathbb{E}_t \left[\sum_{i=1}^{\infty} \theta^{i-1}(1-\theta)\Lambda_{t,t+i} \left(v_{t+i}a_{t+i} + J_{t+i}z_{t+i} - d_{t+i-1} \right) \right]$$

subject to a sequence of budget constraints and no-default constraints. Switching to recursive formulation, an entrepreneur's functional equation can be written as

$$\begin{aligned} V_t(a_t, z_t, d_{t-1}) = \max_{z_{N,t}, d_t} & (1-\theta)\mathbb{E}_t \left[\Lambda_{t,t+1}(v_{t+1}a_{t+1} + J_{t+1}z_{t+1} - d_t) \right] \\ & + \theta \mathbb{E}_t \left[\Lambda_{t,t+1} V_{t+1}(a_{t+1}, z_{t+1}, d_t) \right] \end{aligned} \tag{11}$$

subject to

$$J_t z_{N,t} \leq \pi_t a_t + \frac{1}{R_t} d_t - d_{t-1} \tag{12}$$

$$\mathbb{E}_t \left[\Lambda_{t,t+1} V_{t+1}(a_{t+1}, z_{t+1}, d_t) \right] \geq \psi_A \left(v_t - \pi_t \right) \mathbb{E}_t \left(a_{t+1} \right) + \psi_Z J_t \mathbb{E}_t(z_{t+1}) \tag{13}$$

Equation (12) is the budget constraint, which requires expenditure on new projects, $J_t z_{N,t}$, to be no larger than the cash flow from adopted technologies plus increases in debt. Equation (13) is the no default constraint, requiring the continuation value to exceed the value of defaulting. Given the formulation for technology adoption, the expected number of adopted and unadopted technologies at $t+1$ is given by

$$\mathbb{E}_t(a_{t+1}) = \phi_A a_t + \lambda \left(\phi_Z z_t + z_{N,t} \right) \tag{14}$$

$$\mathbb{E}_t(z_{t+1}) = (1-\lambda) \left(\phi_Z z_t + z_{N,t} \right) \tag{15}$$

The entrepreneur's problem can be solved by first guessing that the value function is linear in each of the individual states:

$$V_t(a_t, z_t, d_{t-1}) = V_{A,t}a_t + V_{Z,t}z_t - V_{D,t}d_{t-1} \tag{16}$$

with the marginal values $V_{A,t}$,$V_{Z,t}$ and $V_{D,t}$ depending only on the aggregate state. One can then proceed by conjecturing that the constraint binds and using undetermined coefficients to solve for the value function, confirming the initial conjecture. Under the parameterization described below, and for reasonable variations around it, the constraint always binds along the balanced growth path.[6]

Given a binding constraint, an entrepreneur's choice for debt d_t and new projects $z_{N,t}$ is given by the following:

$$J_t z_{N,t} = \pi_t a_t + \frac{1}{R_t}\left[\gamma_{A,t}a_t + \gamma_{Z,t}\left(\phi_Z z_t + z_{N,t}\right)\right] - d_{t-1} \tag{17}$$

$$d_t = \gamma_{A,t}a_t + \gamma_{Z,t}\left(\phi_Z z_t + z_{N,t}\right) \tag{18}$$

Equation (18) is a *debt capacity* constraint, where the variables $\gamma_{A,t}$ and $\gamma_{Z,t}$ represent the extent to which adopted and unadopted technologies are collateralizable, respectively.[7] These two variables depend only on aggregates. In particular, declines in expected future asset prices $\{v_{t+i}, J_{t+i}\}_{i=1}^{\infty}$ will generate declines in $\gamma_{A,t}$ and $\gamma_{Z,t}$, since entrepreneurs' incentives to default are enhanced with lower expected asset prices. This leads to a tightening of the constraint on entrepreneurs' debt. Notice that increases in the interest rate R_t also directly tighten the constraint: with total debt due the following period d_t constrained by the entrepreneur's assets, an increase in interest rates directly reduces the resources an entrepreneur can obtain by borrowing.

Aggregation. Since entrepreneurs' decision rules (17) and (18) are linear in all indivual variables (a_t,z_t,d_t and $z_{N,t}$) aggregation is straightforward. Defining uppercase letters to be the aggregate values of their lowercase counterparts, from (17) we obtain an aggregate

[6]See appendix B.1 for details. Roughly speaking, two conditions need to be satisfied in order for the constraint to bind: returns from new projects cannot be too pleadgeable, and investing in new projects needs to be profitable enough. If the first condition is not satisfied, a new project by itself generates enough borrowing capacity to pay for its cost, and therefore the entrepreneur is effectively unconstrained. If the second condition is not satisfied, the entrepreneur would rather not invest at all. Given that there are no diminishing returns at the level of an individual entrepreneur, if it is profitable to invest the entrepreneur will always want to borrow the maximum amount.

[7]See appendix B.1 for the derivation. Notice that unadopted projects inherited from the previous period, z_t, have an additional penality in their pledgeability, due to the fact that they become useless with probability $1 - \phi_Z$.

demand relation for new innovations:

$$J_t Z_{N,t} = \pi_t A_t + \frac{1}{R_t}\left[\gamma_{A,t} A_t + \gamma_{Z,t}\left(\phi_Z Z_t + Z_{N,t}\right)\right] - D_{t-1} \tag{19}$$

The aggregate amount of debt carried over into next period, D_t, is given by the debt carried over by surviving entrepreneurs minus the resources transferred to the entrepreneurs who start out in period $t+1$. I assume that the cash transfer to each new entrepreneur is simply a fraction of the total value of the assets controlled by exiting entrepreneurs, which equals $(1-\theta)\left[v_t A_t + J_t(Z_t + Z_{N,t})\right]$. Accordingly, I set the transfer to new entrepreneurs to fraction $\hat{d}/(1-\theta)$ of this value, where $\hat{d}$ is an exogenous parameter. Thus aggregate entrepreneurial debt at the end of t is

$$D_t = \theta\left[\gamma_{A,t} A_t + \gamma_{Z,t}(\phi_Z Z_t + Z_{N,t})\right] - \hat{d}\left[v_t A_t + J_t(Z_t + Z_{N,t})\right] \tag{20}$$

The aggregate number of intermediates adopted next period is obtained by adding to the existing number those projects attempted today that turn out to be successful. Accordingly, by the Law of Large Numbers the laws of motion for aggregate adopted and unadopted technologies are

$$A_{t+1} = \phi_A A_t + \lambda\left(\phi_Z Z_t + Z_{N,t}\right) \tag{21}$$

$$Z_{t+1} = (1-\lambda)\left(\phi_Z Z_t + Z_{N,t}\right) \tag{22}$$

The Frictionless Benchmark. The frictionless benchmark is the case in which the opportunity to invest in the adoption of new intermediates is directly available to the household, i.e. as with physical capital, the household can directly purchase innovations and receive the benefits if adoption is successful. In that case, the following Euler equation obtains:

$$J_t = \mathbb{E}_t\left\{\Lambda_{t,t+1}\left[\lambda v_{t+1} + (1-\lambda)\phi_Z J_{t+1}\right]\right\} \tag{23}$$

Comin and Gertler (2006) derive a similar equation for optimal adoption. As shown in Appendix B.2, this condition also obtains when there is full enforcement between entrepreneurs and creditors. In that case, entrepreneurial debt becomes irrelevant for aggregate dynamics, the number of projects undertaken by an individual entrepreneur is indeterminate, and $Z_{N,t}$ is pinned down by (23).

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:

$$Z_{N,t}^{P} = N_t^{\eta}(A_t L_{S,t})^{1-\eta} \tag{24}$$

(24) indicates that an innovator using N_t units of final output and $L_{S,t}$ units of skilled labor used can produce $Z_{N,t}^{P}$ new innovations.[8] Innovations sell at price J_t. Note that, as in Romer (1990), (24) 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:

$$J_t = \frac{1}{\eta}\left(\frac{1}{\bar{L}_S}\right)^{\frac{1-\eta}{\eta}}\left(\frac{Z_{N,t}^{P}}{A_t}\right)^{\frac{1-\eta}{\eta}}$$

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

$$N_t = \eta Z_{N,t}^{P} J_t$$

Finally, equilibrium in the market for new innovations requires total demand from entrepeneurs, $Z_{N,t}$, to equal the total amount produced by innovators plus uncompleted projects sold by exiting entrepreneurs:

$$Z_{N,t} = Z_{N,t}^{P} + (1-\theta)\phi_Z Z_t$$

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:

[8] 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).

$$Y_t = \left[\int_0^{A_t} Y_t(s)^{\frac{\vartheta-1}{\vartheta}} ds\right]^{\frac{\vartheta}{\vartheta-1}} \tag{25}$$

Given the aggregator above, demand for each intermediate s is

$$Y_t(s) = \left[\frac{P_t(s)}{P_t}\right]^{-\vartheta} Y_t \tag{26}$$

where the price level P_t is defined as

$$P_t = \left[\int_0^{A_t} P_t(s)^{1-\vartheta} ds\right]^{\frac{1}{1-\vartheta}} \tag{27}$$

Equation (26) 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:

$$Y_t(s) = [u_t(s)K_t(s)]^\alpha L_t(s)^{1-\alpha} \tag{28}$$

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 θ_W of the quarterly wage bill:

$$\kappa_t(s) \geq \theta_W W_t L_t(s) \qquad \theta_W \geq 0$$

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 $\left[1 + \theta_W \left(\frac{R_t-1}{R_t}\right)\right] W_t$, 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.[9] Thus, their objective is to solve

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

[9]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 (26) and (28). Solving the firm's problem yields the following equations:

$$\left[1 + \theta_W \left(\frac{R_t - 1}{R_t}\right)\right] W_t = (1 - \alpha)\frac{Y_t}{L_t} \tag{29}$$

$$R_t^k = \alpha\frac{Y_t}{K_t} + P_{K,t} - \delta(u_t) \tag{30}$$

$$\alpha\frac{Y_t}{u_t} = \delta'(u_t)K_t \tag{31}$$

Per period profits π_t can be shown to be equal to

$$\pi_t = \frac{1}{\vartheta}\frac{Y_t}{A_t} \tag{32}$$

Given free entry into the business of manufacturing any particular type of intermediate, π_t is also the per-period cash flow to an entrepreneur from renting an adopted technology. Finally, combining the aggregator (27) with the equations for intermediates producers one obtains an expression for final output:

$$Y_t = A_t^{\frac{1}{\vartheta-1}}(u_t K_t)^{\alpha} L_t^{1-\alpha} \tag{33}$$

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_t^n be net investment, the amount of investment used for construction of new capital goods:

$$I_t^n = I_t - \delta(u_t)K_t \tag{34}$$

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

The economy-wide capital stock evolves according to[10]

[10]Given the assumptions on $\Phi(\cdot)$, to a first order the evolution of capital along the balanced growth path is the usual $K_{t+1} = [1 - \delta(u_t)] K_t + I_t$.

$$K_{t+1} = K_t + \Phi\left(\frac{I_t^n}{K_t}\right) K_t \tag{35}$$

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

$$\mathbb{E}_{t-1}(P_{K,t}) = \mathbb{E}_{t-1}\left\{\left[\Phi'\left(\frac{I_t^n}{K_t}\right)\right]^{-1}\right\} \tag{36}$$

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

$$\frac{1}{R_t}B_t - B_{t-1} + Y_t = C_t + I_t + N_t \tag{37}$$

B_t is economywide foreign indebtedness, equal to the sum of aggregate family and entrepreneurial debt ($B_t = D_t^F + D_t$). Equation (37) can be derived by combining family and entrepreneur budget constraints with equilibrium conditions.

The description of the model is now complete.

4 Model Analysis

This section presents numerical simulations of the calibrated model. 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 sector disruptions often associated with sudden stop episodes may contribute substantially to the slowdown in productivity growth.

The second experiment compares the properties of the simulated model to a set of time series for Argentina for the period 1950-2005. The emphasis is on illustrating how the novel mechanisms introduced in this paper, endogenous growth and financial frictions, contribute to a more realistic behavior of output and the Solow residual *vis-á-vis* the Argentinian data, especially at medium frequencies.

4.1 Parameter Values

There are a total of twenty-one parameters in the model, of which twelve are standard in the emerging markets business cycles literature. Of the remaining nine, five relate to the endogenous growth process: the adoption probability (λ), the survival rates of adopted and unadopted technologies (ϕ_A and ϕ_Z), the share of materials in the innovation sector (η) and the supply of skilled labor ($\bar{L}_S$). The remaining four parameters relate to the financial market imperfection. They include the survival rate of entrepreneurs (θ), the divertable fractions of assets (ψ_A and ψ_Z), and the transfer rate to new entrepreneurs ($\hat{d}$).

I begin with the conventional parameters. I set the risk aversion parameter σ at 5, as in Gertler et. al. (2007). The habits parameter γ is set at 0.25, a relatively modest amount. As discussed before, I choose ξ, the weight of leisure in the utility function, to deliver a labor supply elasticity of 1/2, a relatively low value. This implies setting $\xi = 0.3$. I set the yearly interest rate in steady state at 2%.

Turning to technology parameters, I set the capital share α to 1/3, and the quarterly depreciation rate of physical capital, δ, equal 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 (δ''/δ'), 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). Regarding the working capital constraint, I set $\theta_W = 2.5$, implying that firms need to pay two and a half quarters worth of the wage bill in advance.[11] 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 0.0003.

I choose the parameter on the intermediate goods aggregator, ϑ, so that output is proportional to TFP along the balanced growth path, which by looking at equation (35) amounts to imposing $(1-\alpha)(\vartheta-1) = 1$. This restriction makes profits per period, π_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).

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 4.8%, similar to the average in East Asia for the pre-crisis period. I set the adoption probability λ to obtain an average diffusion

[11] While this value is slightly above the usual range found in the literature, it is worth stressing that its purpose is to generate a realistic behavior of hours worked in response to a crisis shock – see Neumeyer and Perri (2005) for more on this point. On the other hand, the results regarding the novel mechanism of the paper, namely technology adoption subject to credit constraints, are robust to lower values of this parameter.

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 ϕ_A to deliver an annual obsolescence rate of adopted technologies of 20%, and also assume a somewhat higher value for the obsolescence of unadopted tecnologies, which I set to 25% per year. Finally, based on the presumption that technology production is relatively labor-intensive, I set $\eta = 1/4$, which implies that along the balanced growth path 10% of output is by the innovation sector.

Finally, I turn to the financial sector parameters. I set the entrepreneur survival rate $\theta = 0.995$, implying an expected horizon of entrepreneurs of 50 years. To calibrate the divertable fractions, I assume that it is harder to divert an unadopted technology than a completed project, and for simplicity I set $\psi_Z = \frac{\psi_A}{2}$, but emphasize that results are robust to variations in ψ_Z. I then choose ψ_A and the transfer rate $\hat{d}$ to generate a small spread of 0.5% along the balanced growth path (i.e., distortions due to the financial imperfection are small along the balanced growth path) and a relatively conservative leverage ratio of 50% (debt to assets). The resulting values for ψ_A and $\hat{d}$ are 0.61 and 1×10^{-4}, respectively.

Table 1 reports the values chosen for the model parameters together with a reminder of their meaning.

4.2 Crisis Experiment

I now analyze the effects of an unanticipated increase in the country interest rate. In particular, I consider a 500 basis point increase in r_t that persists as a first-order autoregressive process with a 0.86 coefficient. These magnitudes are close to the evidence for the crisis in South Korea in 1997, as shown by Gertler et. al. (2007). Figure 6 illustrates the time path of the country interest rate as a result of the shock.

Figure 7 summarizes the key results regarding the effects of a financial crisis. It displays the behavior of output, labor productivity and employment following the interest rate shock, relative to the unshocked path of the economy. In the case with frictions in the financing of technology adoption, there is a large permanent component in the decline of output, explained by a permanent decline in labor productivity. The size of the decline in labor productivity is about two thirds of the decline in output, similar to the evidence on the effects of financial crises discussed earlier. The drop in labor productivity is substantially smaller in the case with frictionless adoption, and nonexistent in the case with exogenous growth. As a consequence, in the latter case output fully recovers: after about five years it has returned to the pre-crisis trend. This stands in stark contrast with the empirical evidence on the dynamics following financial crises discussed above, which shows that the aftermath of these episodes tends to be characterized by a lack of recovery. Finally, the behavior of employment is fairly similar across the three versions of the model. The reason is that it is mainly driven by the working capital requirement on intermediates producers, which induces a decline in labor demand as interest rates increase.

Figures 8 and 9 document the mechanism at work behind the results shown in Figure 7. The interest rate shock tightens entrepreneurs' constraints and reduces their access to debt financing, leading to a large decline in the number of new innovations entrepreneurs attempt to adopt, $Z_{N,t}$. The value of unadopted innovations, J_t, displays a large fall relative to the case in which there are no financing frictions, reflecting a slowdown in adoption activity due to tightening constraints. The result is a fall in the aggregate number of innovations that the entrepreneurial sector attempts to adopt, Z_t, which directly translates into a reduction in the rate of new adoptions. As shown in Figure 9, this implies a substantial slowdown in the growth rate of TFP, leading to a permanent drop in this variable relative to its unshocked path.

Figure 10 shows the responses of labor productivity, the measured Solow residual and TFP for the three cases. Focusing on the solid blue line, the permanent decline in TFP induces a permanent decline in labor productivity of similar magnitude. As the third panel shows, the Solow residual falls sharply immediately after the initial shock, while TFP (last panel) follows a more gradual decline. The reason behind the behavior of the Solow residual is a short-run drop in capital utilization. The medium run declines in labor productivity and measured Solow residual, however, are driven by TFP. In fact, the dynamic pattern of labor productivity turns out to be very similar to that of TFP: the reason is that the two opposing forces that make labor productivity depart from TFP in the short run, which are a drop in capital utilization (making labor productivity drop more than TFP) and an increase in the capital-labor ratio due to a drop in labor input (making labor productivity drop less than TFP) turn out to roughly cancel each other. Comparing across the three versions of the model, the bottomline from Figure 8 is that the financial market imperfection contributes substantially in generating labor productivity declines as large and persistent as observed in the data, and that the model with exogenous growth has little hope of being able to match that evidence. The permanent decline in TFP in the case with frictions is quantitatively close to the evidence for South Korea presented above, according to which TFP fell by about 6% relative to trend.

Figure 11 plots the response of a set of standard macroeconomic variables. Overall, the model does a 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). As discussed above, the mechanisms introduced in this paper help in accounting for the slow recovery of output following these episodes. A final point to highlight from Figure 11 is the substantial high frequency 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. The reason for this is the stronger negative response of the growth rate of TFP g, which as in Aguiar and Gopinath (2007) implies a larger movement in permament income, generating a larger decline in consumption relative to income.

4.3 Argentina 1950-2005

Figure 9 plots filtered annual series for Argentina's GDP and Solow residual for the period 1950-2005. The method to isolate medium frequency variation follows Comin and Gertler (2006): the medium-term cycle is defined as fluctuations at frequencies of 50 years and above; the medium-term component isolates movements associated with frequencies between 8 and 50 years. Figure 9 reveals large and persistent medium-term fluctuations in Argentinian GDP, largely accounted for by movements in the Solow residual: from Table 2, the volatility of the Solow residual over the medium-term business cycle relative to that of GDP is 88%, even higher than the corresponding ratio at the high frequency (79%). As Table 3 documents, the correlation between the two series over the medium term is also strong at a value of 0.9, also larger than its high-frequency counterpart (0.84).

To analyze the statistical properties of the three versions of the model economy (financial frictions, frictionless benchmark and exogenous growth), I examine simulated time series from the calibrated model driven by two forces: interest rate shocks and low-persistence labor supply shocks.[12] In particular, I set the variances of the innovations so that the model exactly matches the volatility of Argentinian GDP at the high frequency, and so that each of the shocks explains fifty percent of that volatility.[13] The first order autoregressive parameter of the labor supply shock process is set at .5. The experiment is then to assess the performance of the model at medium frequencies, and to analyze the contribution of financial frictions and endogenous growth to model performance.

[12]It is convenient to think of each of the shocks as a composite of a low volatility component driving fluctuations in normal times, and a "disasters" process which generates a relatively large crisis with a small probability. A large realization of the interest rate shock captures a financial crisis triggered by capital outflows as in the preceding section, and a disaster in the labor supply shock is a simple way to capture a crisis induced by domestic developments. The "disasters" formulation is introduced to enrich the economic interpretation of the model. Given the level of approximation used, all that matters is the overall standard deviation of each of the shocks.

[13]While admittedly arbitrary, this calibration is roughly consistent with the findings in Neumeyer and Perri (2005) and Uribe and Yue (2006) on the role of interest rates in explaining high-frequency fluctuations in emerging economies.

Table 3 reports standard deviations for output, the Solow residual, consumption and investment for the data and for the three versions of the model economy. The case with financial frictions does substantially better at generating medium frequency movements in output and the Solow residual: the volatility of GDP over the medium-term cycle, equal to 7.9% in the data, is 6.47% for the case with financial frictions, while in the frictionless benchmark and in the exogenous growth case it takes values of 5.48% and 5.05%, respectively. Largely responsible for this improved performance is a better ability of the model with frictions to account for medium-run movements in the Solow residual, which displays a volatility over the medium term of 6.96% in the data, versus 4.03% in the model with frictions, 1.71% in the frictionless benchmark, and 1.60% in the exogenous growth case. Further, as Table 3 shows, the model with exogenous growth fails at reproducing the correlation between GDP and the Solow residual at medium frequencies. Finally, both endogenous growth and the financial friction contribute to a more realistic volatility of consumption at all frequencies.

I conclude this section with the bottomline that the case with financial frictions is better able to match important features of the data, especially regarding medium frequency fluctuations in GDP and the Solow residual.

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 also shown to generate reasonable behavior of macroeconomic aggregates, with the financial friction substantially amplifying the response of GDP at high and especially medium frequencies. The mechanism introduced in the paper also implies an amplified short and medium run response of consumption. Finally, the model with frictions is shown to be better able to match Argentine data than a frictionless benchmark and a version with exogenous growth, especially with regard to the behavior of output and the Solow residual at medium frequencies.

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 mechanisms introduced 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[14], 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.

Argentina 1950-2005. Yearly data for consumption and investment from Garcia-Cicco, Pancrazi and Uribe (2009), and for output and total hours worked from the Total Economy Database.

B An Entrepreneur's Problem

B.1 Solution

The problem for an individual entrepreneur is given by equations (11)-(13) in the text. Given the conjecture that the value function is linear in the individual states (equation (16)), one can substitute out the continuation value in the no default constraint (equation (13)). What emerges is a constraint on entrepreneurial debt:

$$d_t \leq \gamma_{A,t} a_t + \gamma_{Z,t} \left(\phi_Z z_t + z_{N,t} \right) \tag{38}$$

where the coefficients $\gamma_{A,t}$ and $\gamma_{Z,t}$ can be interpreted the collateral value of adopted and unadopted technologies. They depend on the value function coefficients as follows:

$$\gamma_{A,t} = \phi_A \frac{\mathbb{E}_t \left\{ \Lambda_{t,t+1} \left[V_{A,t+1} - \psi_A \phi_A v_{t+1} \right] \right\}}{\mathbb{E}_t \left[\Lambda_{t,t+1} V_{D,t+1} \right]} \tag{39}$$

$$\gamma_{Z,t} = \lambda \frac{\mathbb{E}_t \left\{ \Lambda_{t,t+1} \left[V_{A,t+1} - \psi_A \phi_A v_{t+1} \right] \right\}}{\mathbb{E}_t \left[\Lambda_{t,t+1} V_{D,t+1} \right]} + (1 - \lambda) \frac{\mathbb{E}_t \left[\Lambda_{t,t+1} V_{Z,t+1} \right] - \psi_Z J_t}{\mathbb{E}_t \left[\Lambda_{t,t+1} V_{D,t+1} \right]} \tag{40}$$

Notice that it is possible to combine the participation constraint (40) with the entrepreneur's budget constraint (11) to obtain a constraint on total expenditures on new projects, which reads as follows:

[14] http://www.conference-board.org/economics/database.cfm

$$J_t z_{N,t} \leq \pi_t a_t + \frac{1}{R_t}\left[\gamma_{A,t} a_t + \gamma_{Z,t}\left(\phi_Z z_t + z_{N,t}\right)\right] - d_{t-1} \tag{41}$$

The right hand side of (43) is interpretable as an entrepreneur's "collateralizable net worth", that is, the collateral value of her assets (given by the first three terms), plus her current period cash flow from adopted technologies, $\pi_t a_t$, minus her debt inherited from the previous period, d_{t-1}.

Toward obtaining expressions for the value function coefficients in (15), first define the following objects:

$$\omega_{A,t} \equiv \mathbb{E}_t \left\{\Lambda_{t,t+1}\left[(1-\theta)v_{t+1} + \theta V_{A,t+1}\right]\right\} \tag{42}$$

$$\omega_{Z,t} \equiv \mathbb{E}_t \left\{\Lambda_{t,t+1}\left[(1-\theta)\phi_Z J_t + \theta V_{Z,t+1}\right]\right\} \tag{43}$$

$$\omega_{D,t} \equiv R_t \mathbb{E}_t \left\{\Lambda_{t,t+1}\left[(1-\theta) + \theta V_{D,t+1}\right]\right\} \tag{44}$$

Note that (44)-(46) represent marginal "continuation values" from the viewpoint of an entrepreneur who has yet to find out whether he has to exit at the end of the period. Define also

$$\bar{\omega}_t \equiv \lambda \omega_{A,t} + (1-\lambda)\omega_{Z,t} \tag{45}$$

$\bar{\omega}_t$ can be interpreted as the value to the entrepreneur of starting one additional project, which becomes an adopted technology with probability λ and remains unadopted with probability $(1-\lambda)$.

An entrepreneur's problem simplifies to

$$V_t(a_t, z_t, d_{t-1}) = \max_{z_{N,t}} \left[\bar{\omega}_t - \omega_{D,t} J_t\right] z_{N,t} + \left(\phi_A \omega_{A,t} + \omega_{D,t}\pi_t\right) a_t + \phi_Z \bar{\omega}_t z_t - \omega_{D,t} d_{t-1} \tag{46}$$

subject to (43). The Lagrange multiplier for this problem, denoted l_t, is

$$l_t = \frac{\bar{\omega}_t - \omega_{D,t} J_t}{J_t - \frac{\gamma_{Z,t}}{R_t}} \tag{47}$$

Thus, for the constraint to bind it is sufficient that $\bar{\omega}_t - \omega_{D,t} J_t > 0$ and $J_t - \frac{\gamma_{Z,t}}{R_t} > 0$. If the former does not hold then it is not profitable for the entrepreneur to invest, while if the latter is not satisfied an entrepreneur can finance a new project by simply mortgaging it and does not need to borrow against her other assets. Along the balanced growth path of the calibrated model, both conditions hold.[15]

Given a binding constraint, $z_{N,t}$ is given by (43) at equality. One can then combine the resulting expression for $z_{N,t}$ with the value function (48) to solve for the coefficients $V_{A,t}$, $V_{Z,t}$ and $V_{D,t}$ in (15), which depend only on aggregate variables:

$$V_{A,t} = \omega_{D,t}\pi_t + \phi_A \omega_{A,t} + \left[\pi_t + \frac{\gamma_{A,t}}{R_t}\right] l_t \tag{48}$$

$$V_{Z,t} = \phi_Z \bar{\omega}_t + \frac{\phi_Z \gamma_{Z,t}}{R_t} l_t \tag{49}$$

$$V_{D,t} = \omega_{D,t} + \frac{1}{R_t} l_t \tag{50}$$

To build some intuition on what determines the "pledgeability" coefficients $\gamma_{A,t}$ and $\gamma_{Z,t}$, imagine first that $\lambda = 1$ (potential technologies become adopted in one period with certainty). Then from (42) we have that $\gamma_{A,t} = \gamma_{Z,t}$: since a potential technology will become a usable design the following period with certainty, it has the same "collateral" value for creditors as an already adopted technology. Notice that with $\theta > 0$, for every future date there is a positive probability that the entrepreneur will exit in that particular period, and therefore expectations of the full sequence of asset prices $\{v_{t+i}\}_{i=1}^{\infty}$ matter for determining the collateral value of assets. Likewise, with $\lambda < 1$ (adoption is not certain) the expected future "franchise value" J_{t+i} (i.e. the price an entrepreneur gets at time of exit for the projects he has not managed to complete) will lead to declines in $\gamma_{Z,t}$, the degree to which uncompleted projects are collateralizable. In the aggregate, the latter feature opens the door to "adverse feedback" effects, where reductions in entrepeneurs' expenditure lead to lower expected future prices J_{t+i}, which drives down $\gamma_{Z,t}$, which reduces entrepeneur expenditure further.

B.2 Full Enforcement

This section shows that equation (23) obtains when there is full enforcement, i.e. when the default option for entrepreneurs yields negative infinity utility. We have the following result:

Proposition: *If the value of defaulting is negative infinity, the aggregate number of new projects $Z_{N,t}$ is determined by* $1 = \mathbb{E}_t \left[\Lambda_{t,t+1} \frac{\lambda v_{t+1} + (1-\lambda)\phi_Z J_{t+1}}{J_t}\right]$.

Proof. Since the incentive constraint cannot bind, we must have $\bar{\omega}_t = \omega_{D,t} J_t$. We make the following conjectures: $V_{D,t} = 1$,$V_{A,t} = v_t$ and $V_{Z,t} = \phi_Z J_t$ $\forall t$. Given these conjectures, the

[15]Note that the Lagrange multiplier does not depend on any entrepreneur-specific variables.

Euler equation $1 = \mathbb{E}_t\left[\Lambda_{t,t+1}\frac{\lambda v_{t+1}+(1-\lambda)\phi_Z J_{t+1}}{J_t}\right]$ immediately follows from $\bar{\omega}_t = \omega_{D,t}J_t$. Since we must also have $l_t = 0$, from equations (50)-(52) the conjectures are verified. ■

C The Complete Model

C.1 Conventional Part

Production function:

$$Y_t = A_t^{\frac{1}{\vartheta-1}}(u_t K_t)^{\alpha} L_t^{1-\alpha} \tag{51}$$

Marginal utility of consumption:

$$U_{C,t} = u_{C,t} - \beta\gamma\mathbb{E}_t\left(u_{C,t+1}\right) \tag{52}$$

$$u_{C,t} = (1-\xi)(C_t - \gamma C_{t-1})^{-[(1-\xi)\sigma+\xi]}(1-\mu_t^W L_t)^{\xi(1-\sigma)} \tag{53}$$

Labor market equilibrium:

$$\frac{\xi(C_t-\gamma C_{t-1})^{(1-\xi)(1-\sigma)}(1-\mu_t^W L_t)^{\xi(1-\sigma)-1}}{U_{C,t}} = \frac{1}{1+\theta_W\left(\frac{R_t-1}{R_t}\right)}(1-\alpha)\frac{Y_t}{L_t} \tag{54}$$

Stochastic discount factor:

$$\Lambda_{t,t+1} = \frac{\beta U_{C,t+1}}{U_{C,t}} \tag{55}$$

International bond Euler Equation:

$$1 = \mathbb{E}_t\left(\Lambda_{t,t+1}\right)R_t \tag{56}$$

Capital Euler Equation (demand for capital):

$$1 = \beta\mathbb{E}_t\left(\Lambda_{t,t+1}\frac{\alpha\frac{Y_{t+1}}{K_{t+1}} + P_{K,t+1} - \delta(u_{t+1})}{P_{K,t}}\right) \tag{57}$$

Supply of capital:

$$\mathbb{E}_{t-1}(P_{K,t}) = \mathbb{E}_{t-1}\left\{\left[\Phi'\left(\frac{I_t^n}{K_t}\right)\right]^{-1}\right\} \tag{58}$$

Net investment:

$$I_t^n = I_t - \delta(u_t)K_t \tag{59}$$

Capital accumulation:

$$K_{t+1} = K_t + \Phi\left(\frac{I_t^n}{K_t}\right)K_t \tag{60}$$

Optimal utilization:

$$\alpha\frac{Y_t}{u_t} = \delta'(u_t)K_t \tag{61}$$

Market clearing:

$$\frac{1}{R_t}B_t - B_{t-1} + Y_t = C_t + I_t + N_t \tag{62}$$

International bond price:

$$R_t = r + e^{r_t} + \psi\left[e^{\frac{B_t - B}{Y_t}} - 1\right] \tag{63}$$

Interest rate shock:

$$r_t = \rho_r r_{t-1} + \sigma_r \epsilon_t^r \tag{64}$$

C.2 Endogenous Growth and Financial Frictions Part

Profits:

$$\pi_t = \frac{1}{\vartheta}\frac{Y_t}{A_t} \tag{65}$$

Value:

$$v_t = \pi_t + \phi_A \mathbb{E}_t(\Lambda_{t,t+1}v_{t+1}) \tag{66}$$

New projects:

$$J_t Z_{N,t} = \pi_t A_t + \frac{1}{R_t}\left[\gamma_{A,t}A_t + \gamma_{Z,t}\left(\phi_Z Z_t + Z_{N,t}\right)\right] - D_{t-1} \tag{67}$$

Debt:

$$D_t = \theta \left[\gamma_{A,t} A_t + \gamma_{Z,t}(\phi_Z Z_t + Z_{N,t})\right] - \hat{d}\left[v_t A_t + J_t(Z_t + Z_{N,t})\right] \tag{68}$$

Adopted technologies:

$$A_{t+1} = \phi_A A_t + \lambda \left(\phi_Z Z_t + Z_{N,t}\right) \tag{69}$$

Unadopted technologies:

$$Z_{t+1} = (1-\lambda)\left(\phi_Z Z_t + Z_{N,t}\right) \tag{70}$$

Price of innovations:

$$J_t = \frac{1}{\eta}\left(\frac{1}{\overline{L}_S}\right)^{\frac{1-\eta}{\eta}} \left(\frac{Z_{N,t} - (1-\theta)\phi_Z Z_t}{A_t}\right)^{\frac{1-\eta}{\eta}} \tag{71}$$

Materials used in innovation sector:

$$N_t = \eta[Z_{N,t} - (1-\theta)\phi_Z Z_t] J_t \tag{72}$$

In the frictionless benchmark, the following equation holds:

$$J_t = \mathbb{E}_t \left\{\Lambda_{t,t+1}\left[\lambda v_{t+1} + (1-\lambda)\phi_Z J_{t+1}\right]\right\} \tag{73}$$

C.3 Detrending

A stationary system can be obtained from the equations in the previous section by redefining the variables that exhibit growth as deviations from trend. In particular, and under the restriction that $(1-\alpha)(\vartheta - 1) = 1$, the system above has a balanced growth path along which $Y_t, K_t, I_t, C_t, N_t, B_t, D_t, Z_{N,t}, Z_t$ grow in proportion to A_t, and prices v_t, J_t, π_t, hours L_t and utilization u_t are stationary. The growth rate of TFP, $g_t \equiv A_{t+1}/A_t$, is also a stationary variable, and it is given by

$$g_t = \phi_A + \lambda\left[\phi_Z \frac{Z_t}{A_t} + \frac{Z_{N,t}}{A_t}\right] \tag{74}$$

Deviations from trend of Z_t and $Z_{N,t}$ lead to changes in the growth rate g_t.

The simulation results reported in Section 4 are obtained by first solving for the steady state of the stationary system, and then computing approximate loglinear dynamics around the steady state.

D The Effect of Working Capital and Consumption Habits

Figures 13 and 14 report the behavior of the model without the working capital requirment on intermediates producers and without habit formation in consumption, respectively. Without working capital, labor rises on impact. The reason is an outward shift in labor supply, due to the wealth effect. Without consumption habits, consumption displays a sharp decline as the shock impacts, contrary to the hump-shaped response observed in the data. However, the behavior of TFP is relatively insensitive to the removal of these two features of the model. The reason is that TFP is driven by the impact of the shock on asset prices and on entrepreneurs' borrowing constraints, which is relatively unaffected by the presence of working capital or habits.

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Table 1: Calibration

Symbol	Value	Description
Conventional		
$1/Q$	$(1.02)^{1/4}$	Interest rate
σ	5	Risk aversion
ξ	0.3	Weight of leisure
h	0.25	Habits
δ	0.025	Capital depreciation
α	1/3	Capital share
δ''/δ'	0.15	Elasticity of depreciation to utilization
ϑ	2.5	Demand elasticity for intermediates
$\Phi''(I^n/K)$	0.25	Elasticity of P_k to I^n/K
θ_W	2.5	Working capital requirement
ψ	0.0003	Elasticity of interest rate to foreign debt
B/Y	0.2	Foreign debt to output
Growth		
λ	0.08	Probability of adoption
$1-\phi_A$	0.0543	Obsolescence of adopted technologies
$1-\phi_Z$	0.0694	Obsolescence of unadopted technologies
η	0.25	Materials share in innovation sector
$\overline{L}_S$	To generate $\mathrm{g}^4 = 1.048$	Skilled labor supply
Financial Frictions		
θ	0.995	Survival rate
ψ_A	0.61	Divertable fraction of adopted technologies
ψ_Z	0.305	Divertable fraction of unadopted technologies
$\hat{d}$	1×10^{-4}	Transfer to new entrepreneurs

Table 2: Standard Deviations and *Corr*(Solow Residual$_t$, GDP$_t$), Model vs. Data

	High Frequency (0-8)				Medium-Term Cycle (0-50)				Medium Frequency (8-50)			
Standard Deviations	Data	Financial Frictions	Frictionless Benchmark	Exogenous Growth	Data	Financial Frictions	Frictionlessk Benchmark	Exogenous Growth	Data	Financial Frictions	Frictionless Benchmark	Exogenous Growth
Output	3.42	3.42	3.25	3.13	7.9	6.47	5.48	5.05	7.05	5.36	4.27	3.82
Solow Residual	2.69	1.19	0.89	0.92	6.96	4.03	1.71	1.60	6.39	3.80	1.42	1.27
Consumption	4.6	4.42	3.91	3.31	8.35	8.18	7.19	6.00	6.84	6.67	5.85	4.84
Investment	11.29	9.70	9.40	9.11	19.77	16.42	15.50	15.00	20.57	12.80	11.90	11.50
Corr(Solow Residual$_t$, GDP$_t$)	0.84	0.93	0.99	0.96	0.9	0.85	0.87	0.68	0.92	0.87	0.81	0.50

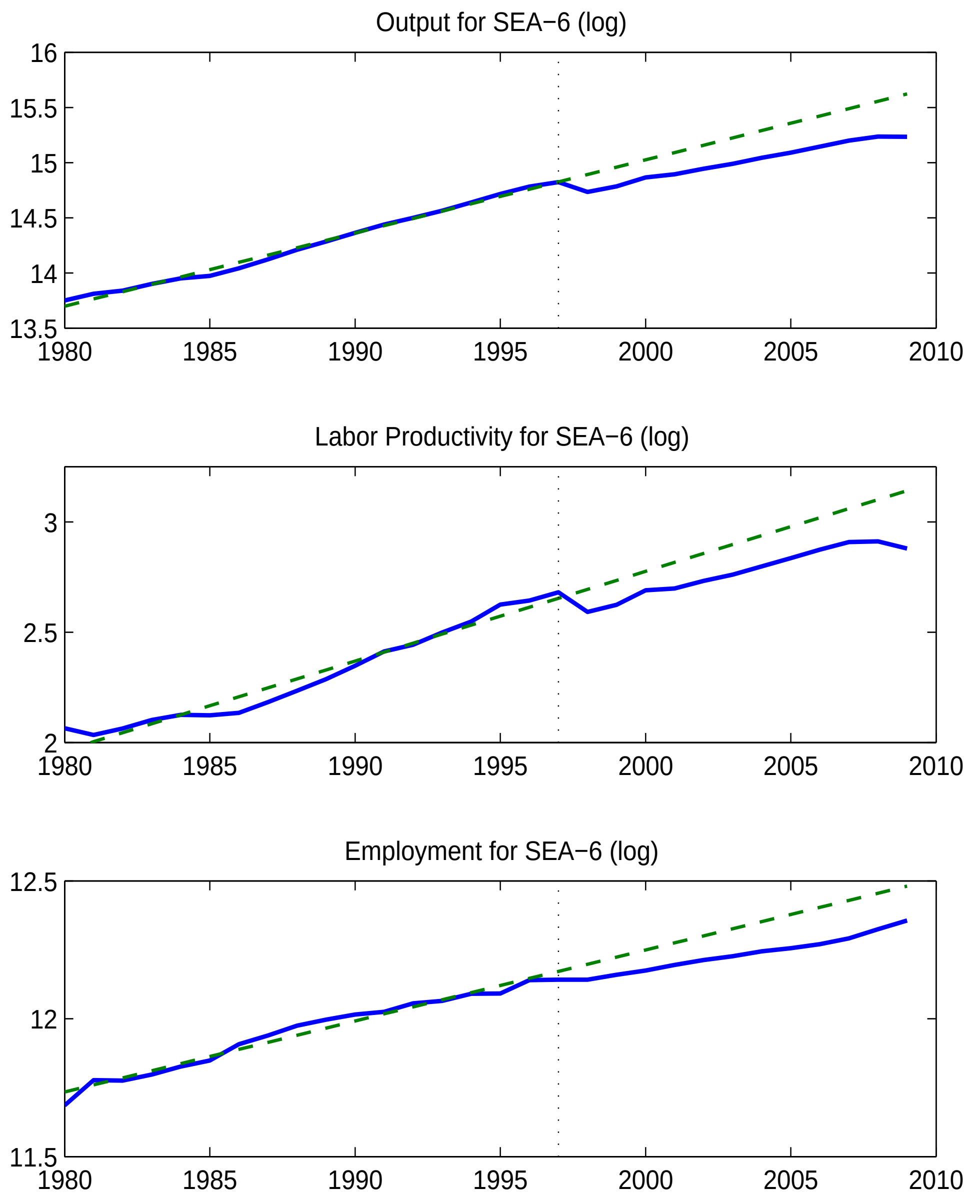

Figure 1: Total output, employment and output per employed worker (logs) for group of 6 South East Asian countries (Indonesia, Malaysia, Phillipines, Korea, Thailand and Hong Kong).

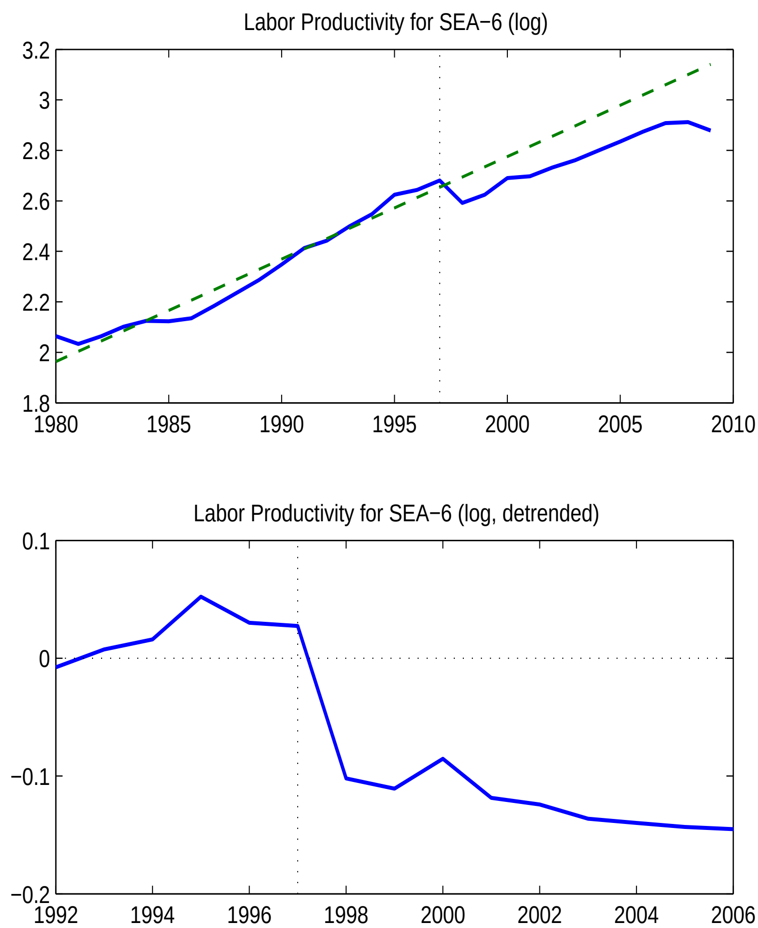

Figure 2: Labor productivity (log) for group of 6 South East Asian countries (Indonesia, Malaysia, Phillipines, Korea, Thailand and Hong Kong).

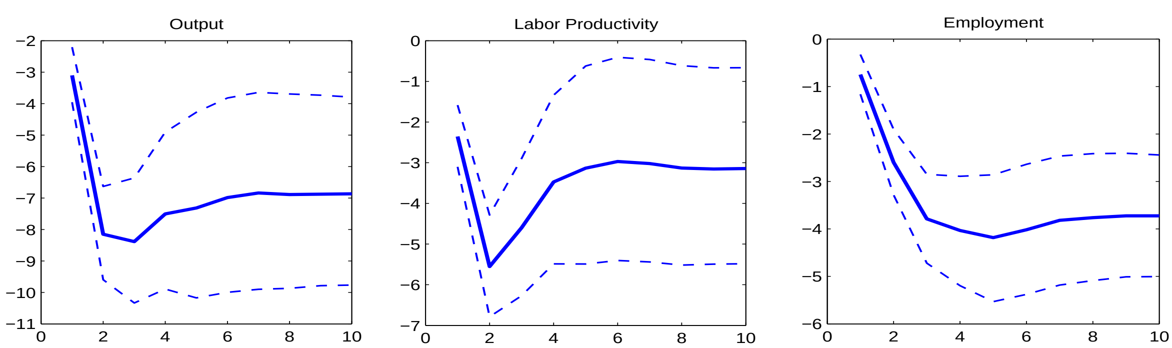

Figure 3: Estimated impulse responses to a banking crisis. Time measured in years.

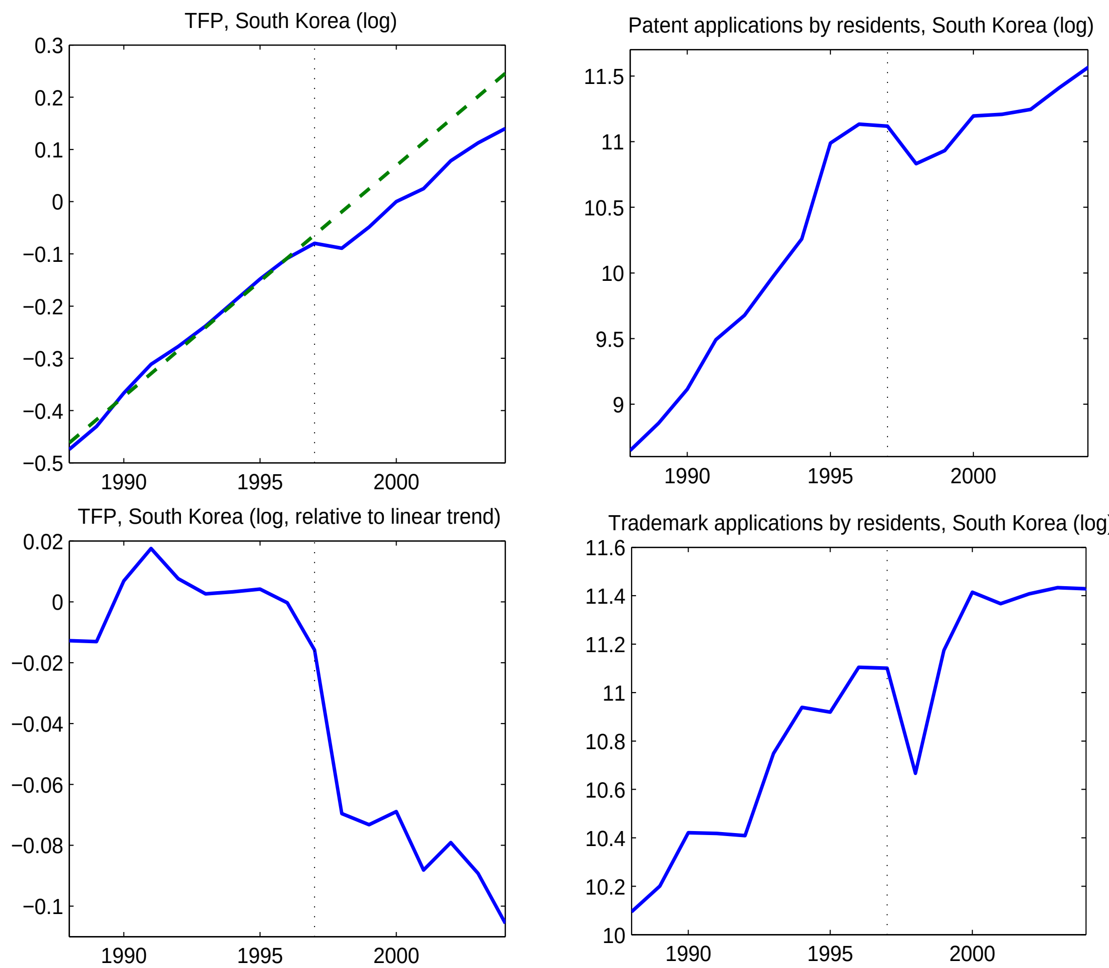

Figure 4: TFP, patents and trademarks, South Korea.

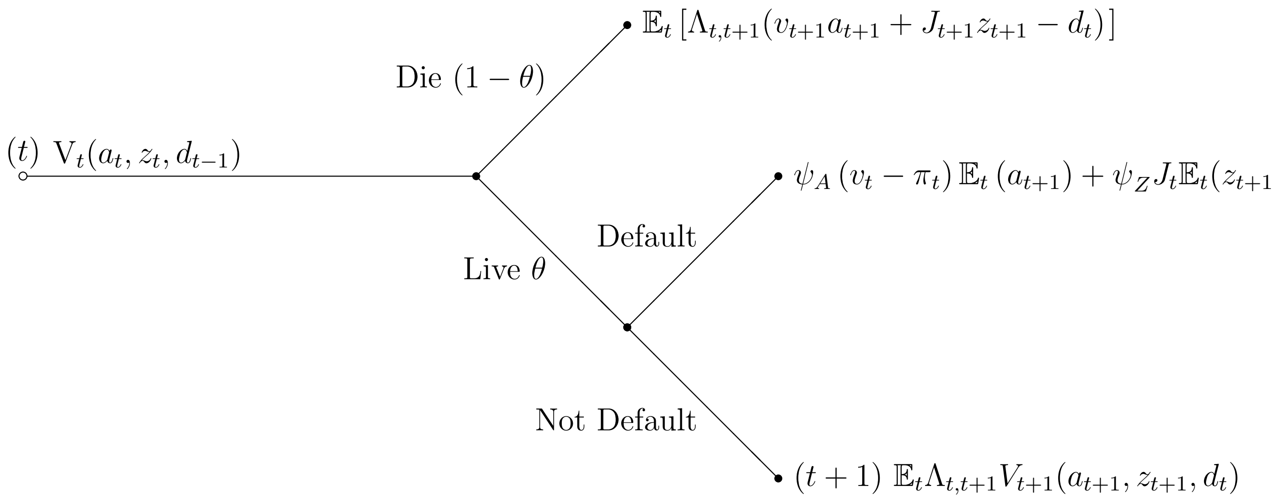

Figure 5: An entrepreneur's problem – period-t timing.

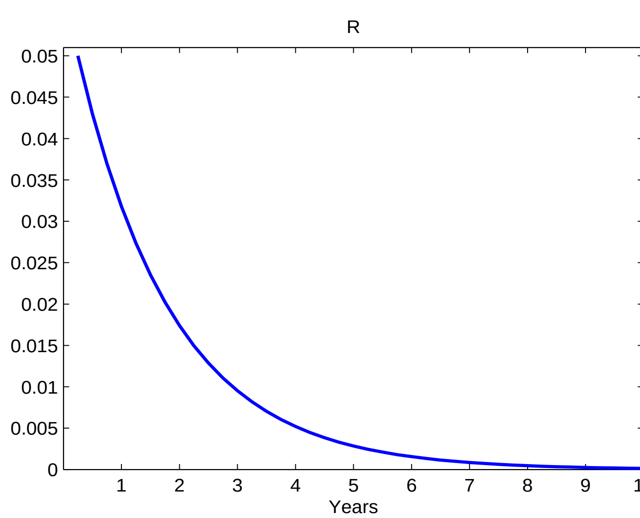

Figure 6: Interest rate shock.

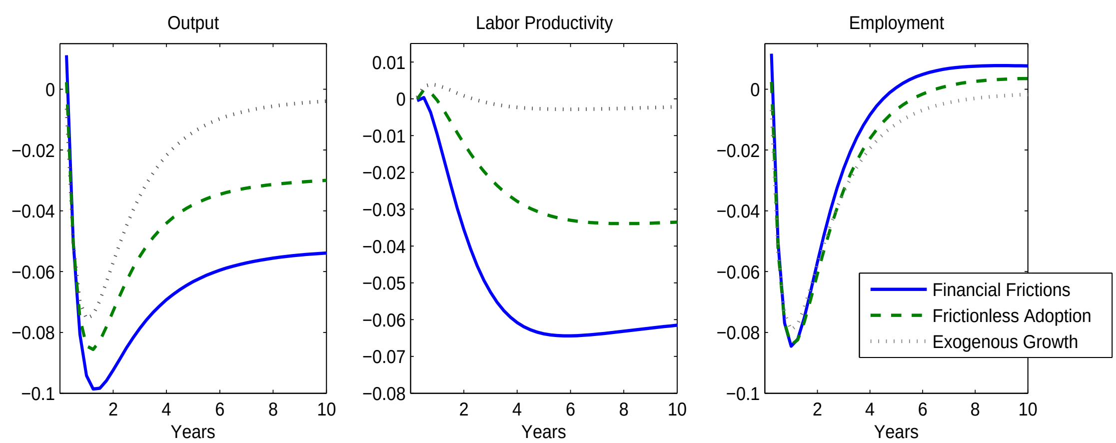

Figure 7: Responses of output, labor productivity and employment to interest rate shock.

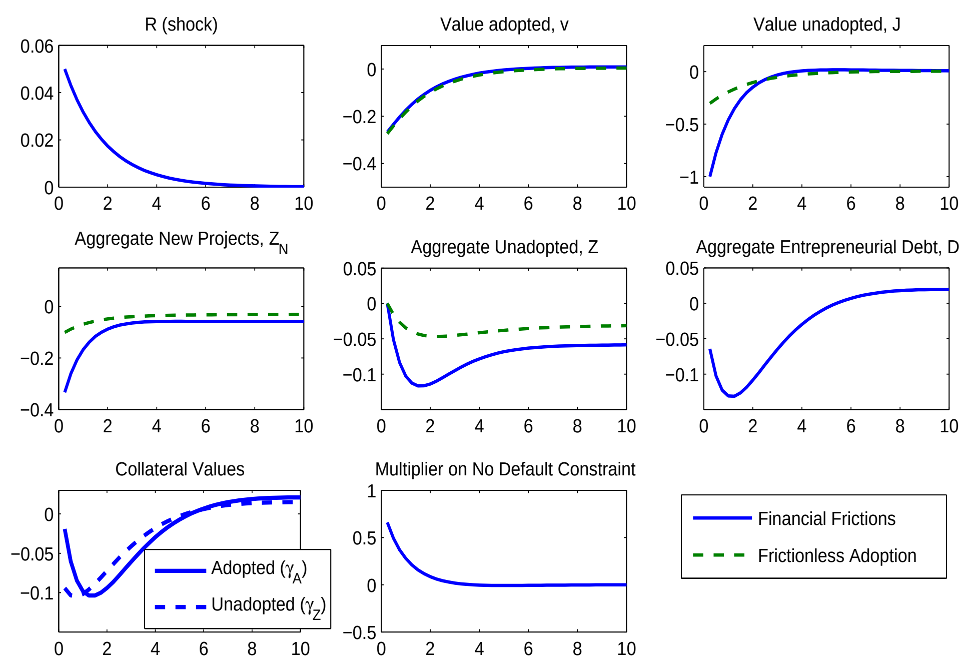

Figure 8: Impulse responses to interest rate shock, endogenous growth and financial frictions variables. Time measured in years.

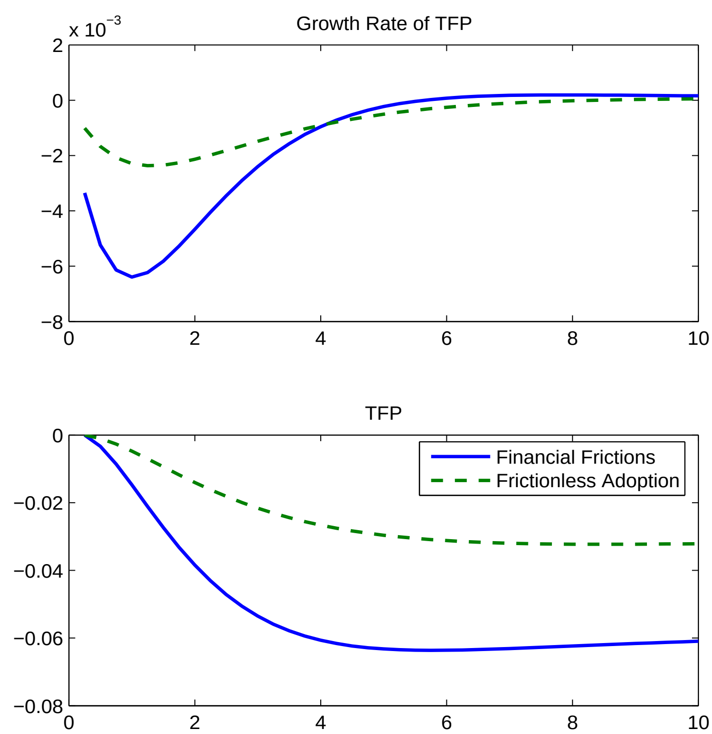

Figure 9: Impulse responses to interest rate shock, TFP growth rate and TFP. Time measured in years.

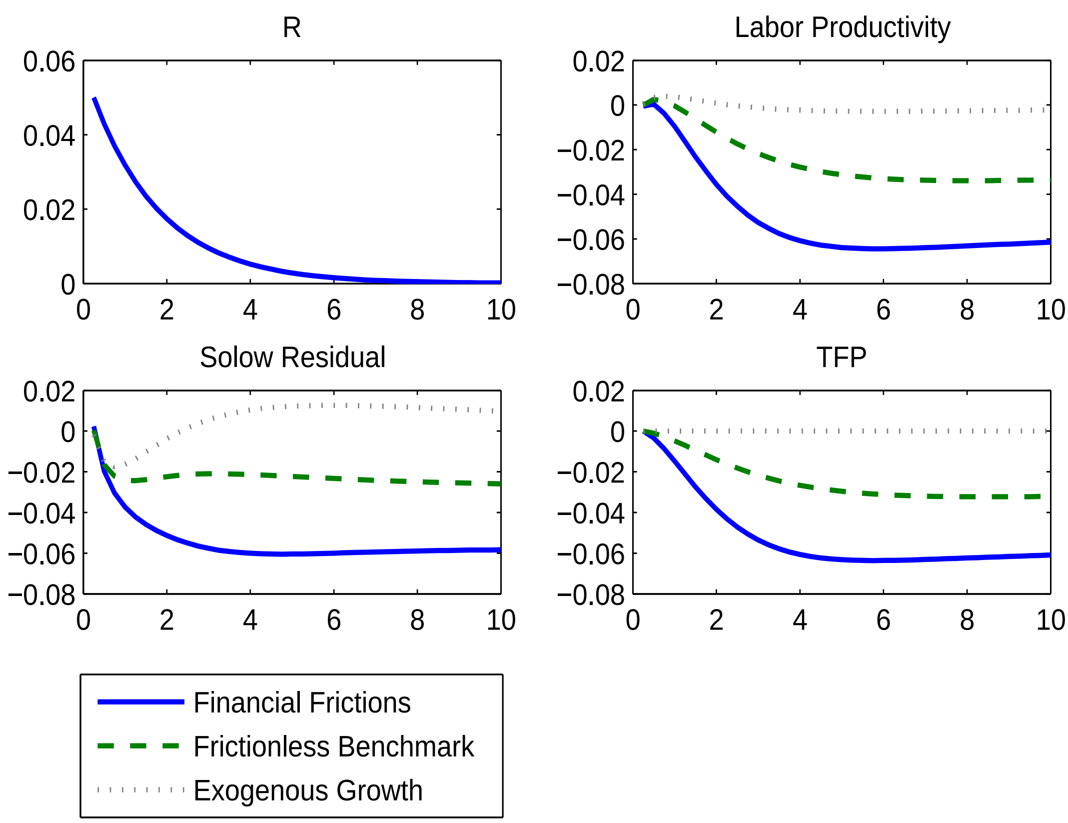

Figure 10: Impulse responses of labor productivity, Solow residual and TFP to interest rate shock. Time measured in years.

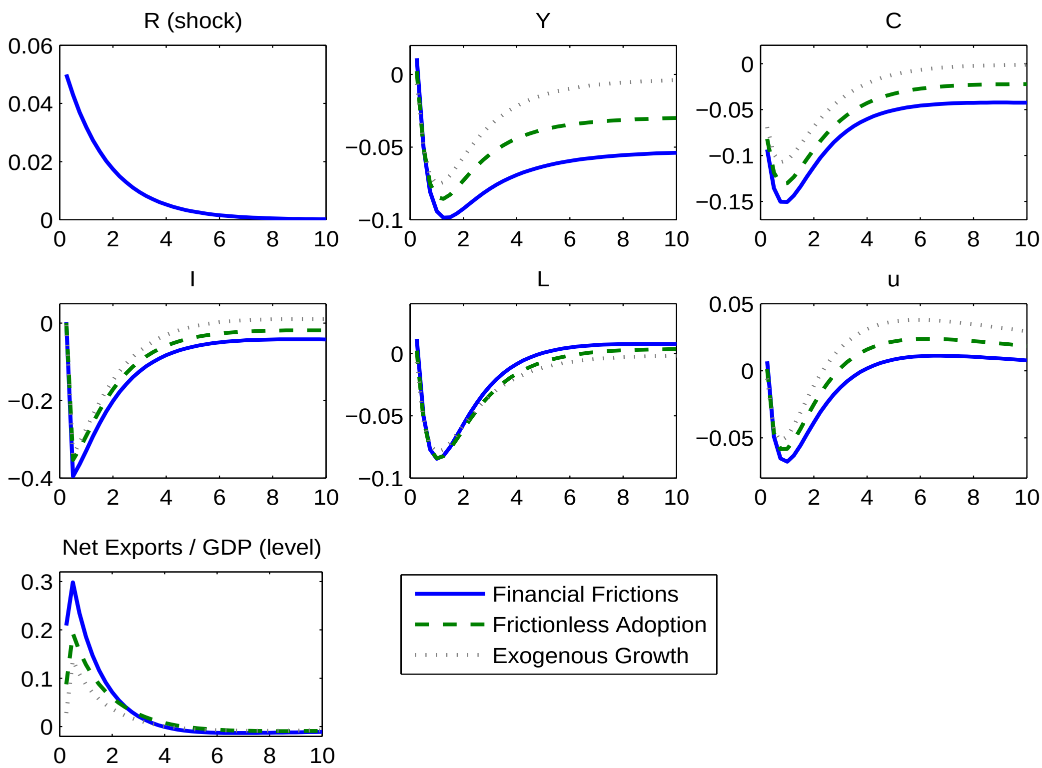

Figure 11: Impulse responses to interest rate shock, standard macroeconomic variables. Time measured in years.

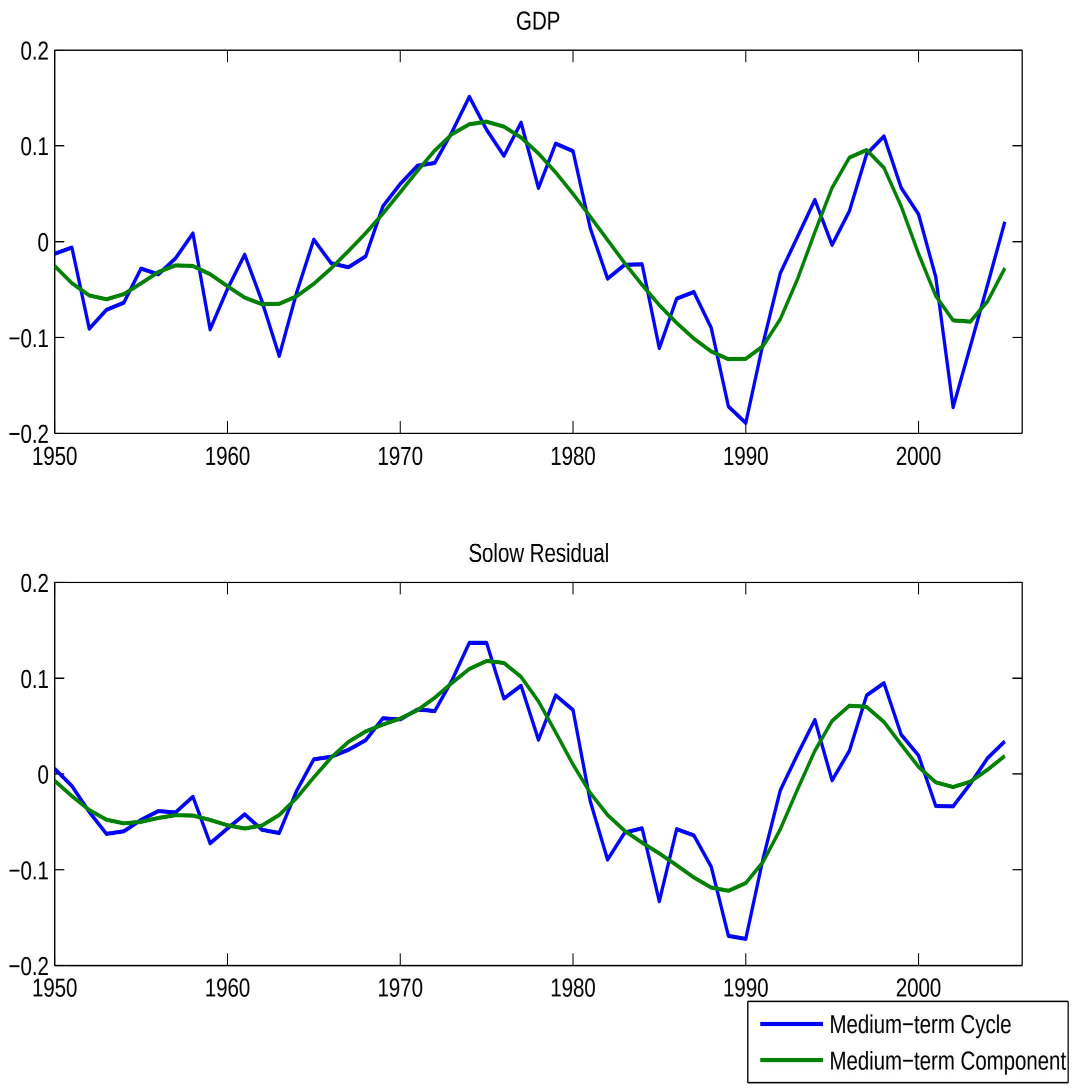

Figure 12: GDP and Solow Residual for Argentina 1950-2005. Medium-term cycle defined as variation at frequencies below 50 years. Medium-term component isolates variation at frequencies between 8 and 50 years. Both are computed using a band-pass filter.

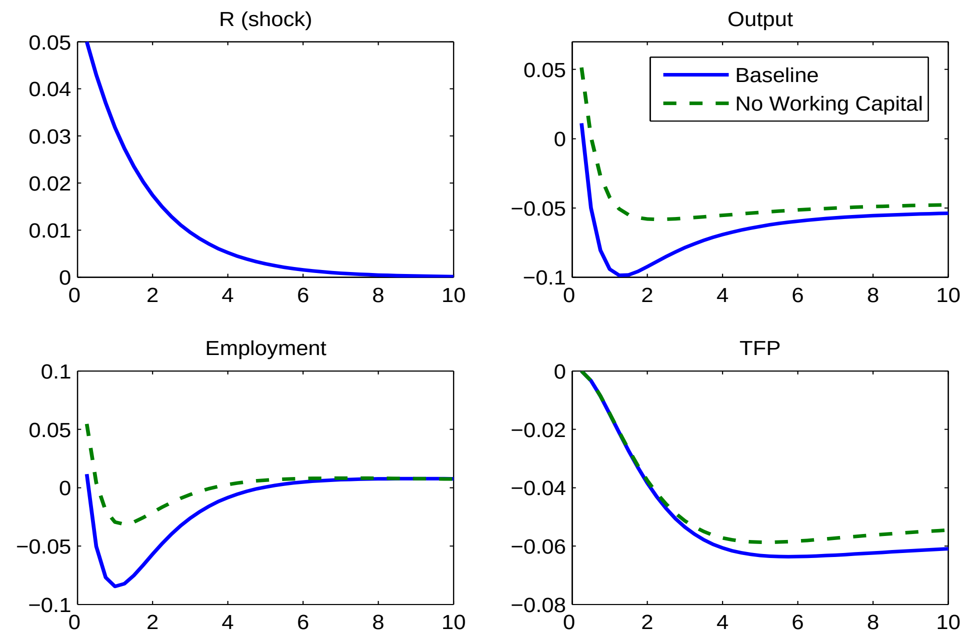

Figure 13: Effect of working capital.

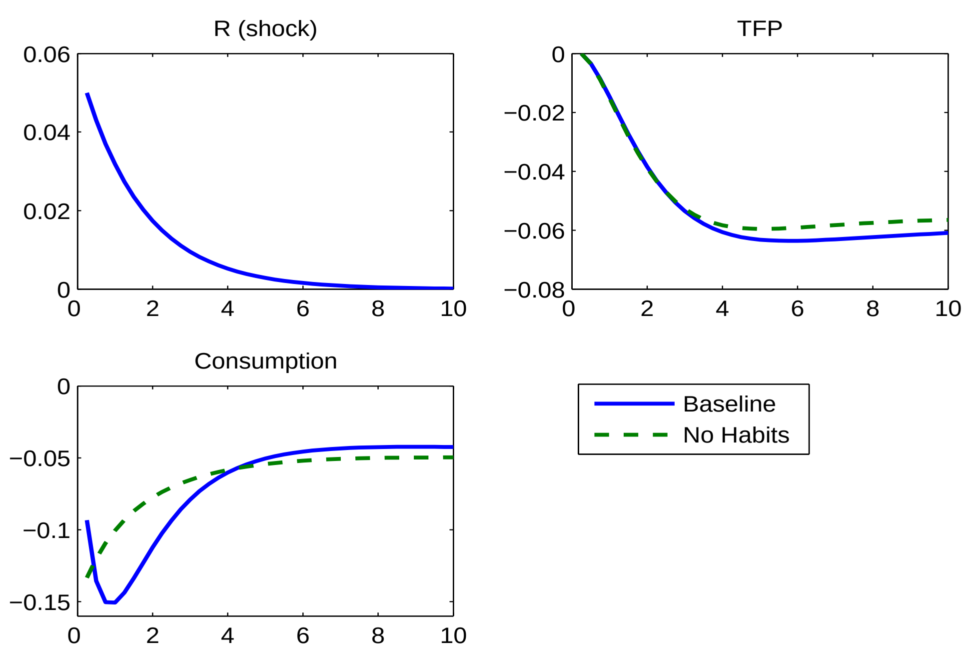

Figure 14: Effect of consumption habits.