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Regime Switching Interest Rates and Fluctuations in Emerging Markets*

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Abstract

We estimate regime switching models for emerging market interest rates and embed the obtained nonlinear dynamics in a small open economy model with a financial friction. We show that the presence of an infrequent regime characterized by high level/high volatility of interest rates and the tightening of financial constraints is key to account for the empirical regularities specific to emerging markets, including the high volatility of consumption relative to output and a strongly countercyclical trade balance-to-output ratio. The model accounts for the dynamics of sudden stops and matches the autocorrelation function of the trade balance-to-output ratio as well as the cross-correlations between the main macroeconomic aggregates and interest rates. Our findings suggest that interest rate shocks and financial frictions are essential for explaining emerging market fluctuations, but mostly because of their effects in crisis episodes.

JEL classification: E32, F32, F41

Keywords: regime switching model, peso problem, sudden stops, small open economy

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1 Introduction

Many emerging economies' business cycle fluctuations notably differ from those of developed small open economies: they are characterized by (1) a higher volatility of macroeconomic variables, (2) a strongly countercyclical trade balance, (3) consumption volatility exceeding output volatility and (4) a more volatile and strongly countercyclical real interest rate.[1] In addition, many emerging economies experience infrequent but traumatic current-account reversals or sudden stops.[2] In this paper we show that, within the framework of the standard small open economy business cycle model, the potential for an abrupt and severe disruption in emerging markets' access to foreign lending is essential to account for both the main empirical regularities of the business cycles, as well as the crisis dynamics of sudden stops episodes observed in the data.

We provide evidence of the regime switching properties of the price that summarizes the external financial conditions for a small open economy: the real interest rate faced in international bond markets. As in Neumeyer and Perri (2005), the real interest rate we consider is constructed from Emerging Markets Bond Index (EMBI) data. Emerging economies' access to international borrowing is best characterized by a real interest rate alternating between a low level/low volatility regime and a high level/high volatility regime, the latter being a low-probability event in the line of a peso problem or a rare disaster as discussed in Barro (2006). We then embed an equivalent non-linear stochastic process in a version of the neoclassical small open economy model of Mendoza (1991) or Correia, Neves and Rebelo (1995) with two main extensions: first, we include an intermediate input essential for the domestic production process and a working capital constraint that requires firms to hold an amount of non-interest-bearing liquid assets proportional to the purchase of intermediate goods. This financial friction is essential to account for the countercyclicality of interest rates as well as the behavior of the trade balance. Second, we include variable capacity

[1] For a documentation of these regularities see, for instance, Neumeyer and Perri (2005) and Aguiar and Gopinath (2007).

[2] The term sudden stop has been used by Calvo (1998) to refer to sudden reversals in capital flows to emerging economies.

utilization, which, as in Meza and Quintin (2007), is important to account for the large contraction in aggregate activity during sudden stops. Apart from an exogenous interest rate process, the only other source of uncertainty is a transitory technology shock. The model is calibrated to Argentinean data and solved using a global nonlinear solution algorithm. We also present results for two alternative versions of the model: one with fixed capacity utilization and another in which we allow the strength of the financial friction to be regime dependent. Our main findings are threefold:

1. The empirical regularities of emerging market business cycles can be explained by exogenous fluctuations in interest rates. The feature of variable capacity utilization magnifies the contribution of interest rate shocks to aggregate volatility.

2. The effects of interest rate movements are almost entirely due to the presence of an infrequent crisis regime, during which both the level and volatility of interest rates increase dramatically.

3. The ability of the model to match the data depends mainly on the presence of a sufficiently strong financial friction but only during the crisis regime.

In our benchmark model for Argentina, we find that removing exogenous fluctuations in interest rates lowers the volatility of output growth by 57%. With fixed utilization the reduction in output volatility is 18% and with regime dependent financial frictions it is 59%. In all three models, virtually all of the contribution of interest rate fluctuations, and therefore also the ability to match the empirical regularities of the business cycle, is accounted for by the infrequent crisis regime in interest rates.

It seems plausible that some movements in the country risk component of the interest rate are caused by domestic shocks. However, we lack a convincing theory that endogenizes country spreads and filling that gap is beyond the scope of this paper. Instead, we follow a long standing tradition and feed the model with an exogenous interest rate process, which features hikes as large and infrequent as observed in the data.[3] Under this assumption, the occurrence of crises in our model is reminiscent of the literature on sudden stops that follows the approach of Calvo (1998), according to which large changes in the portfolio of international investors, vastly unrelated to the evolution of domestic fundamentals, are the main driver of crises in emerging economies.[4] However, differently from what is generally assumed in that literature, the shocks in our model lie within the set of realizations that rational agents consider possible and can anticipate. In this context, we find that a small deviation from the standard neoclassical model, a working capital constraint only active in crises episodes, is enough to produce sudden stops dynamics nested together with normal business cycle fluctuations as we observe in emerging markets.

The key mechanism that generates a significant role for interest rates in our model is the finance constraint. As pointed by Neumeyer and Perri (2005), this type of friction generates a transmission mechanism by which interest rate fluctuations affect the level of economic activity that is essential in explaining the cross-correlations of macroeconomic aggregates with interest rates. While our analysis also highlights the relevance of this friction, it explores its interaction with the nonlinearities in the external financial conditions faced by emerging economies. We fit a nonlinear regime switching process to unfiltered interest rates, which is not only a more accurate characterization of emerging market interest rates, but is also more appropriate to study tranquil times as well as crisis episodes within a unified framework. Our quantitative analysis does not rely on a local (linear) approximation of the underlying model, which may be problematic since the volatility of emerging markets implies at times large deviations from any chosen approximation point. In addition, our approach recognizes that rational agents incorporate the possibility of a rare but economically significant crisis into their behavior even in tranquil times (i.e. build up precautionary savings), and allows for effects stemming from changes in the volatility of the interest rate shocks. Our methodology is therefore better suited to evaluate the empirical performance of the model not only

[3] An exogenous real interest rate is assumed in Neumeyer and Perri (2005), Aguiar and Gopinath (2006), Uribe and Yue (2006), Fernández-Villaverde et al. (2008) and many more.

[4] Some examples include Cook and Devereux (2006a,b) and Gertler, Gilchrist and Natalucci (2007) among others.

on the basis of unconditional sample moments, but also on the basis of the dynamics in a crisis episode. We show for Argentina that the ability of the RBC model augmented with financial frictions to match the empirical business cycle moments relies almost entirely on the occurrence of crises, and that the role of interest rates and financial frictions is minimal during tranquil times. We also find that accounting for nonlinearities in the interest rate process, as well as including variable capacity utilization, greatly strengthens the case of Neumeyer and Perri (2005) for an important role of interest rates in explaining emerging market fluctuations.

A closely related line of research introduced by Aguiar and Gopinath (2007) argues that emerging market business cycles are well described by a frictionless RBC model featuring only permanent and transitory shocks to productivity. In contrast, our benchmark model economy, while successful in matching the relevant moments, does not have permanent technology shocks and assigns a more limited role to transitory technology shocks. Our results can be reconciled with those of Aguiar and Gopinath (2007) by the fact that an interest rate increase leads to a drop in measured TFP because of the financial friction and through a reduction in capacity utilization. We find in our model that a temporary shift to a high interest rate regime leads to a very persistent deviation below trend of output, consumption and investment. However, our model is able to address a key counterfactual prediction of the frictionless RBC models pointed out by Garcia-Cicco, Pancrazi and Uribe (2006), namely that it does a poor job of explaining the behavior of the trade balance. Whereas in the data this ratio displays an autocorrelation function of a stationary autoregressive process with relatively mild persistence, the frictionless RBC model with productivity shocks implies almost a random walk. Our model instead produces trade balance-to-output ratio dynamics very much in line with the empirical evidence.

As crises are associated not only with a change in the level but also in the volatility of interest rates, our paper is related to the literature analyzing the effect of uncertainty shocks. Bloom (2007) introduces second moment shocks in a standard firm-level model and finds that large temporary uncertainty shocks produce sharp drops and rebounds in activity. In the context of a standard RBC open economy model, of particular interest is a paper by Fernández-Villaverde, Guerrón-Quintana, Rubio-Ramírez and Uribe (2008) in which the authors assess the role of time varying volatility in the interest rate process. As we do, these authors allow for both level and volatility shifts in the interest rate process. Based on a local third order approximation of the model solution, they also conclude that nonlinearities in the interest rate process matter quantitatively for emerging market fluctuations, in particular for the behavior of consumption. The key difference between their paper and ours, besides the specification of the interest rate process, is the fact that their analysis is conducted within the context of the standard frictionless model, whereas our includes a financing friction.

2 Regime Switching in Emerging Market Interest Rates

In this section we document the evidence for the regime switching behavior of interest rates for a sample of emerging economies and, in particular, for Argentina. For our purposes, the most relevant interest rate is the expected real borrowing rate faced by the domestic private sector, for which we would need data on both private sector borrowing rates and expected domestic inflation. As Neumeyer and Perri (2005) argue, the high variability of inflation in emerging economies makes it extremely difficult to construct a reliable measure of expected inflation. In addition, emerging markets private sector interest rates are not readily available for samples of sufficient size. We therefore follow Neumeyer and Perri (2005), Uribe and Yue (2006), Fernández-Villaverde et al. (2008) and others by constructing the domestic rate from the combination of a measure of the international risk free rate and data on sovereign bond spreads. Furthermore, Arellano and Kocherlakota (2008) and Mendoza and Yue (2008) provide evidence showing that sovereign interest rates and rates faced by firms in emerging economies are closely related; for Argentina, in particular, these studies report correlations above 0.8. We compute sovereign bond monthly average spreads using the EMBI daily data reported by J.P.Morgan since December 1993. For Argentina we also extend the series backward relying on quarterly bond return data used by Neumeyer and Perri (2005). The international risk free real rate is obtained by subtracting the average year-on-year gross inflation of the U.S. GDP Implicit Deflator over the previous year from the annual yield on 3-month U.S. Treasury bills.[5]

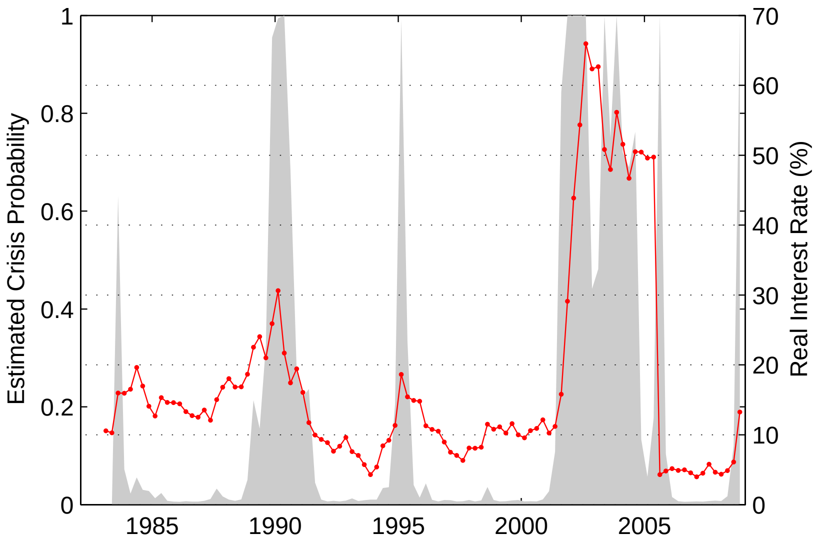

Figure 1: Real interest rate in Argentina (quarterly data). Grey areas denote estimated probability of the crisis state.

Figure 1 displays the extended quarterly real interest rate for Argentina and Figure 2 depicts the monthly real interest rate for a sample of emerging economies. Summary statistics and sample coverage are reported in Tables 1 and 2 respectively. For most of the countries in our sample, one or more episodes stand out in which the interest rate jumps to a much higher level and seems more volatile than outside of these episodes. Distinctive examples include the periods following the 1994 crisis in Venezuela, the Mexican Tequila crisis of 1994, the Russian default of 1998, the 1998 financial crisis in Ecuador, the repercussions of the 1997-1998 Asian crisis, the 1999 and 2002 crises in Brazil and the 2001 Argentinean crisis; some of these episodes, like the Tequila crisis or the Russian default, have clearly spread beyond domestic borders. These crisis episodes are also reflected in the sample statistics: not only are the sample standard deviations generally high,

[5]Section A of the Appendix contains further details on the data construction.

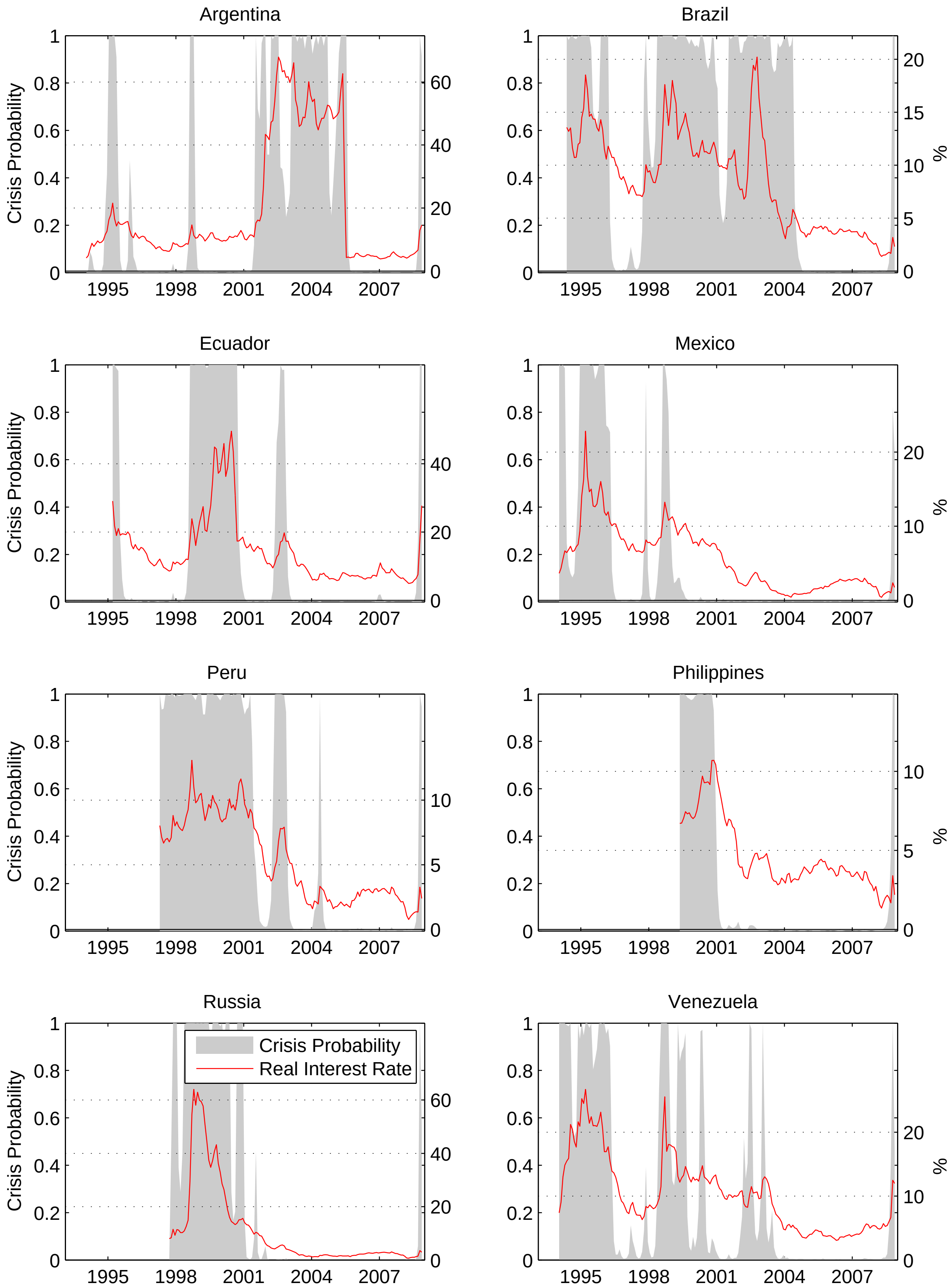

Figure 2: Real interest rates in selected emerging markets (monthly data). Grey areas denote estimated probability of the crisis state.

the sample averages are also considerably higher than the medians (the average ratio of the mean over the median across countries is 1.6 in our sample). Based on this informal evidence, simple linear models seem unlikely to be the best approximation of the interest rate dynamics faced by these and many other emerging economies. Our alternative is the following Markov-Switching autoregressive model,

$$r_t = \nu(s_t) + \rho_r r_{t-1} + \sigma(s_t)\varepsilon_t \;\;,\;\; \varepsilon_t \sim \text{i.i.d}\, N(0,1) \tag{1}$$

where r_t is the real interest rate and ε_t is a white noise random variable.[6] The state s_t is assumed to follow an irreducible ergodic two-state Markov process with transition matrix Π. This specification allows the intercept, $\nu(s_t)$, and the standard deviations of the statistical innovation, $\sigma(s_t)$, to be regime dependent, but assumes that the persistence parameter $0 \leq \rho_r < 1$ is the same across regimes.[7] More precisely, $\nu(s_t)$ and $\sigma(s_t)$ are parameter shift functions stating the dependence of the parameters on the realization of one of two regimes, which we denote by C (crisis) and T (tranquil):

$$\{\nu(s_t), \sigma(s_t)\} = \begin{cases} \{\nu_T, \sigma_T\} & \text{if } s_t = T \\ \{\nu_C, \sigma_C\} & \text{if } s_t = C \end{cases}$$

There are therefore seven parameters to be estimated: ν_T, ν_C, ρ_r, σ_T, σ_C and two out of the four elements in the transition matrix Π.[8]

Table 1 shows the maximum likelihood estimates of the Markov-Switching model for the quar-

[6]We refer to Hamilton (1994) and Krolzig (1997) for a detailed description of Markov-Switching models.

[7]We also allowed for the persistence parameter to be regime dependent. However, based on results from a formal hypothesis test using Argentinean quarterly data we could not reject the null hypothesis that the intercept is the same across regimes. More precisely, we constructed a likelihood ratio test statistic and, since it has a nonstandard distribution in this context due to a nuisance parameter problem, computed critical values by performing Monte Carlo simulations (2,000 repetitions). The p-value for the test statistic is 0.34 so we assumed further on the persistence parameter to be regime-independent, keeping a more parsimonious model specification.

[8]To be more precise, there is an additional parameter to estimate: the starting period state probability, which we estimate with the smooth probability for period one; see Hamilton (1990).

Table 1: Argentina Real Interest Rate: Summary Statistics and Markov-Switching Model Estimates (Quarterly Data).

Summary Statistics:			
Sample		Q1/1983	Q4/2008
Observations		104	
Min.		3.94%	
Max.		65.95%	
Mean		17.55%	
Median		12.13%	
Standard Deviation:		15.21%	
Markov Switching AR Estimation:			
Parameters:		$s_t = T$	$s_t = C$
Intercept	$\widehat{\nu}(s_t)$	0.39	1.73
		[0.4061]	[3.2577]
Autoregressive	$\widehat{\rho}_r$	0.9634	
		[0.0356]	
Unconditional Mean	$\widehat{\nu}(s_t)/(1-\widehat{\rho}_r)$	10.59	47.30
Standard Deviation	$\widehat{\sigma}(s_t)$	1.66	12.07
		[0.4647]	[5.9722]
Transition matrix	$\widehat{Pr}\{s_{t+1} = T \| s_t\}$	0.91	0.32
		[0.046]	
	$\widehat{Pr}\{s_{t+1} = C \| s_t\}$	0.09	0.68
			[0.3077]
Ergodic Probabilities		77%	23%
Linearity Test:			
	LR	61.81	
	p-value	0.0001	

Numbers in brackets are standard errors of estimates, computed with the Newey-West estimator. The p-value of the likelihood ratio statistic is obtained by Monte Carlo simulations (10,000 repetitions) terly real interest rate in Argentina between 1983Q1 and 2008Q4. According to our estimates, in the tranquil regime the real interest rate averages 10.6% with a 1.7% standard deviation for the shocks while in the crisis regime it averages 47.3% and the standard deviation for the shocks is 12%. The tranquil regime is estimated to occur on average 77% of the time and is therefore much more frequent. However, each quarter there is an estimated 9% probability for Argentina of moving to the crisis regime. Once it enters the crisis regime, on average it stays there three to four quarters. The estimated smooth probabilities of the crisis regime are shown as grey areas in Figure 1. The empirical model assigns significant crisis probabilities in all of the known turbulent periods faced by the Argentinean economy during our sample: the end of the exchange rate stabilization plan in the first half of 1980s, the crisis-hyperinflation in the late 1980s and early 1990s, the aftermath of the 1994 Tequila crisis and the end of the convertibility plan (currency board), sovereign default and subsequent crisis in the last quarter of 2001. Also, the ongoing global financial crisis is clearly reflected in the estimated crisis probabilities in the last two observations, 2008Q3 and 2008Q4. Finally, at the end of Table 1 we include the results from testing formally the hypothesis that the process is a standard linear AR(1) against the alternative of the Markov-Switching model using a likelihood ratio test statistic. The value of the likelihood ratio for our sample is 61.35 while the 1% critical value is 22.35, so we can strongly reject the null hypothesis of linearity.[9]

In Table 2 we report the results from estimating the same restricted model for the sample of emerging economies. Similar to the results for Argentina's extended sample, the estimation identifies a crisis regime characterized by a higher average interest rate (from 3 to 20 times higher than in the tranquil regime) and higher standard deviation of the shocks (ranging from 2 to 17 times higher). Except for Brazil, the tranquil regime is estimated to occur much more frequently than the crisis one. For Peru the crisis regime is almost as frequent as the tranquil regime. For the remaining countries the estimated ergodic probability for the tranquil regime ranges from 68% to 84%. Finally, for all of them the linearity test rejects the null hypothesis of linearity at the 1%

[9]As pointed out by Hansen (1992) the test statistic has a nonstandard distribution in this context due to a nuisance parameters problem, so we computed critical values by performing 10,000 Monte Carlo simulations.

Table 2: Real Interest Rate for a Sample of Emerging Economies, Data Statistics and Markov-Switching Model Estimates (Monthly Data).

		Argentina		Brazil		Ecuador		Mexico	
Summary Statistics:									
Sample		12/1993-11/2008		04/1994-11/2008		02/1995-11/2008		12/1993-11/2008	
Range (%)		3.8	67.9	1.4	20.2	4.9	49.6	0.4	22.8
Mean (%)		19.7		8.6		14.4		5.6	
Median (%)		10.7		8.9		11.0		4.3	
Std. dev. (%)		19.4		4.6		9.5		4.3	
Markov Switching AR Estimation:									
Parameters:		$s_t = T$	$s_t = C$	$s_t = T$	$s_t = C$	$s_t = T$	$s_t = C$	$s_t = T$	$s_t = C$
Intercept	$\widehat{\nu}(s_t)$	0.26	1.25	0.08	0.46	0.57	2.69	0.04	0.68
Autoregressive	$\widehat{\rho}$	0.97		0.96		0.93		0.97	
Unconditional Mean	$\widehat{\nu}(s_t)/(1-\widehat{\rho})$	10.18	49.66	1.99	11.36	7.79	36.50	1.35	24.32
Standard Deviation	$\widehat{\sigma}(s_t)$	0.75	7.28	0.28	1.46	0.83	5.47	0.36	2.20
Transition Matrix	$\widehat{\pi}$	0.94	0.06	0.94	0.06	0.97	0.03	0.97	0.03
		0.13	0.87	0.05	0.95	0.08	0.92	0.15	0.85
Ergodic Probabilities		68%	32%	45%	55%	77%	23%	84%	16%
Linearity Test (p-value LR test)		0.0000		0.0002		0.0000		0.0000	

		Peru		Philippines		Russia		Venezuela	
Summary Statistics:									
Sample		03/1997-11/2008		04/1999-11/2008		08/1997-11/2008		12/1993-11/2008	
Range (%)		0.8	13.1	1.3	10.7	0.7	63.9	3.1	26.7
Mean (%)		5.3		4.7		10.8		10.2	
Median (%)		4.0		3.8		3.1		9.5	
Std. dev. (%)		3.2		2.2		15.4		5.7	
Markov Switching AR Estimation:									
Parameters:		$s_t = T$	$s_t = C$	$s_t = T$	$s_t = C$	$s_t = T$	$s_t = C$	$s_t = T$	$s_t = C$
Intercept	$\widehat{\nu}(s_t)$	0.22	1.07	0.26	0.84	0.12	2.50	0.31	1.51
Autoregressive	$\widehat{\rho}$	0.88		0.91		0.93		0.94	
Unconditional Mean	$\widehat{\nu}(s_t)/(1-\widehat{\rho})$	1.89	9.06	3.00	9.65	1.62	33.72	5.02	24.32
Standard Deviation	$\widehat{\sigma}(s_t)$	0.29	0.80	0.31	0.64	0.33	5.87	0.52	2.58
Transition Matrix	$\widehat{\pi}$	0.96	0.04	0.99	0.01	0.96	0.04	0.93	0.07
		0.06	0.94	0.05	0.95	0.11	0.89	0.17	0.83
Ergodic Probabilities		57%	43%	81%	19%	70%	30%	72%	28%
Linearity Test (p-value LR test)		0.0022		0.0062		0.0000		0.0000	

The p-values of the likelihood ratio statistics are obtained by Monte Carlo simulations (5,000 repetitions).

confidence level. Although the estimates based on monthly data are relatively imprecise because the small size of the sample, we do find evidence that the results for Argentinean quarterly sample extend to other emerging markets: the real interest rate is best characterized as alternating between a more frequent low level/low volatility regime and an infrequent high level/high volatility regime.

3 The Model Economy

The model is that of a small open economy that faces stochastic shocks to productivity and the real interest rate, very similar to Mendoza (1991), Correia, Neves and Rebelo (1995) or Schmitt-Grohé and Uribe (2003). Both households and domestic firms trade a non-contingent discount real bond. As in Neumeyer and Perri (2005), Mendoza (2006) and Uribe and Yue (2006), the latter trade in the asset because of the presence of a working capital constraint: firms need to hold an amount of non-interest-bearing liquid assets equivalent to a given fraction of their intermediate inputs purchases.

Households and Preferences. The economy is populated by identical, infinitely-lived households with preferences described by

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left(c_t/\Gamma_t - \zeta \frac{h_t^{1+\psi}}{1+\psi}\right)^{1-\gamma} - 1}{1-\gamma} \ , \ 0<\beta<1, \gamma>1, \psi>0, \zeta>0 \tag{2}$$

where $c_t \geq 0$ denotes consumption and $h_t \geq 0$ is time spent in the workplace. The momentary utility function is of the form proposed by Greenwood, Hercowitz and Huffman (1988). With this specification, optimal labor effort depends only on the contemporaneous real wage. These preferences are popular in small open economy models because they generate more realistic business cycles moments (Correia et al., 1995). They also facilitate our numerical solution procedure by eliminating a root-finding operation. Households supply labor and capital services, receive factor payments and make consumption, saving and investment decisions. Γ_t measures the level of laboraugmenting technology and enters utility to ensure balanced growth. Households own a stock of capital $k_t \geq 0$, and provide capital services $k_t^s \geq 0$ equal to the product of the capital stock and the rate of capacity utilization $u_t \geq 0$. The households' budget constraint in period t is

$$c_t + x_t + d_t \leq R_t^{-1} d_{t+1} + w_t h_t + r_t^k u_t k_t \quad , \tag{3}$$

where x_t are resources for investment and d_{t+1} is the households' foreign debt position in a one-period non-contingent discount bond which is traded at price $1/R_t < 1$, r_t^k is the rental rate of capital services and w_t is the real wage. Our calibrated parameters are such that $\beta/g < 1/R$ holds, where $1/R$ is the long-run average bond price, which is necessary for a well-defined stochastic stationary equilibrium. Long-run solvency is enforced by imposing an upper bound on foreign debt, $d_{t+1} < \Gamma_t D$, precluding households from running Ponzi-type schemes. In practice, we set the value of D high enough such that this constraint never binds in practice.

We assume that $R_t = 1 + r_t$ when $d_{t+1} \geq 0$ where the interest rate r_t is given by (1). We also assume that if $d_{t+1} < 0$, i.e. if domestic households become creditors in international markets, the interest rate faced by the households is $R_t = \min\{1 + r_t, \bar{R}\}$ where $\bar{R} > 1$. Without this assumption, households have strong incentives to save and accumulate unrealistic amounts of bonds when the real interest rate jumps to crisis levels. In contrast, Argentina has always been a net debtor in our sample period: according to the data of Lane and Milesi-Ferretti (2007), the net foreign asset-to-GDP ratio from 1980 to 2004 has fluctuated between -9% to -72%. Although during the Argentinean crises domestic agents do increase saving, in practice they do so by investing in very safe foreign assets, which pay a much lower interest rate than the borrowing rate faced by domestic households and firms. The upper bound on the return to international lending is intended to capture this feature.

The law of motion for capital is

$$k_{t+1} = x_t + \left(1 - \delta - \eta \frac{u_t^{1+\omega}}{1+\omega}\right) k_t - \frac{\phi_k}{2}\left(\frac{k_{t+1}}{gk_t} - 1\right)^2 k_t \ , \eta > 0 \ , \omega > 0 \tag{4}$$

As in Baxter and Farr (2001), the rate of capital depreciation depends positively on capital utilization. There is a quadratic capital adjustment cost where $g \geq 1$ is the economy's average productivity growth factor.

The households' problem is to choose state-contingent sequences of c_t, h_t, x_t, u_t, k_{t+1} and d_{t+1} to maximize expected utility (2), subject to the nonnegativity constraints, the budget constraints (3), the borrowing constraints and the law of motion for capital (4), for given prices w_t, r_t^k and R_t and initial values k_0 and d_0.

Firms and Technology. At time t a representative firm rents capital services k_t^s and, in combination with labor input h_t and an intermediate input m_t, produces z_t of a final good according to the production function

$$z_t = A_t \left[\mu^{1-\rho} m_t^{\rho} + (1-\mu)^{1-\rho} \left(\nu (k_t^s)^{\alpha} (\Gamma_t h_t)^{1-\alpha}\right)^{\rho}\right]^{\frac{1}{\rho}} \tag{5}$$

$$\Gamma_t = g\Gamma_{t-1} \ , \ 0 < \alpha < 1 \ , \ 0 \leq \mu < 1 \ , \ \rho < 1, \nu > 0 \ . \tag{6}$$

where A_t is the stochastic level of productivity. The firm is entirely owned by domestic households and all factor markets are perfectly competitive. Both intermediate and final goods are traded internationally. Whether the intermediate good is being produced domestically or is imported from abroad is irrelevant and, for simplicity, we assume that the relative price of the intermediate input in terms of the final good is unity.[10] As in Uribe and Yue (2006), production is subject to a financing constraint requiring final goods producing firms to hold an amount κ_t of a non-interest bearing asset as collateral. We assume that κ_t must be a proportion $\varphi \geq 0$ of the cost of the intermediate

[10]An alternative assumption is that the relative price is an exogenous random variable. In that case, fluctuations in this price are isomorphic to fluctuations in A_t.

good inputs:

$$\kappa_t \geq \varphi m_t \tag{7}$$

This way of modeling the financing friction has conceptually the same effects as in Neumeyer and Perri (2005), but greatly facilitates the nonlinear solution procedure. The representative firm's distribution of profits at period t is:

$$\pi_t = z_t - w_t h_t - r_t^k k_t^s - m_t - \kappa_t + \kappa_{t-1} \ , \tag{8}$$

The firm's problem is to choose state-contingent sequences for k_t^s, h_t, m_t and κ_t in order to maximize the present discounted value of expected profits distributed to the households:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \pi_t \ , \tag{9}$$

subject to the financing constraints in (7) and taking as given all prices w_t, r_t^k and the representative household's marginal utility of consumption, denoted by λ_t.

Equilibrium An equilibrium is a set of infinite sequences for prices r_t^k, w_t and allocations c_t, h_t, x_t, u_t, m_t, κ_t, k_{t+1}, d_{t+1} such that households and firms solve their respective problems given initial conditions k_0 and d_0 for given sequences of A_t and R_t, and labor, asset and goods markets clear. A balanced growth equilibrium is an equilibrium where c_t/Γ_t, h_t, x_t/Γ_t, u_t, m_t/Γ_t, k_{t+1}/Γ_t, d_{t+1}/Γ_t are stationary variables. Henceforth, we denote the detrended variables by a hat. Detrended GDP in equilibrium can be expressed as

$$\hat{y}_t \quad = \quad \mathcal{A}_t(A_t, q_t) \left(u_t \frac{\hat{k}_t}{g} \right)^{\alpha} h_t^{1-\alpha} \tag{10a}$$

where

$$\mathcal{A}_t(A_t, q_t) = \nu \left(\frac{A_t^{\frac{\rho}{\rho-1}} - \mu(1+\varphi q_t)^{\frac{\rho}{\rho-1}}}{1-\mu} \right)^{\frac{\rho-1}{\rho}} \tag{10b}$$

$$q_t = \frac{R_t - 1}{R_t} > 0 \tag{10c}$$

The term $\mathcal{A}_t(A_t, q_t)$ corresponds to measured TFP corrected for factor utilization, and q_t denotes the opportunity cost of funds for the firm. An increase in R_t raises q_t and lowers $\mathcal{A}_t(A_t, q_t)$. A smaller elasticity of substitution $1/(1-\rho)$ between intermediate inputs and value added, and a higher value of φ both magnify the negative effect of interest rates on total factor productivity. The other equilibrium conditions implied by the households' and firms' optimality conditions include

$$\lambda_t = \left(\hat{c}_t - \zeta \frac{h_t^{1+\psi}}{1+\psi} \right)^{-\gamma} \tag{11}$$

$$\zeta h_t^{\psi} = (1-\alpha) \frac{\hat{y}_t}{h_t} \tag{12}$$

$$\eta u_t^{\omega} = \alpha \frac{g \hat{y}_t}{u_t \hat{k}_t} \tag{13}$$

$$\lambda_t = \frac{\beta}{g} \mathrm{E}_t \left[\lambda_{t+1} \right] R_t \tag{14}$$

$$\lambda_t \left(1 + \frac{\phi_k}{g} \left(\frac{\hat{k}_{t+1}}{\hat{k}_t} - 1 \right) \right) = \frac{\beta}{g} \mathrm{E}_t \left[\lambda_{t+1} \left(\alpha \frac{g \hat{y}_{t+1}}{\hat{k}_{t+1}} + 1 - \delta - \eta \frac{u_{t+1}^{1+\omega}}{1+\omega} + \frac{\phi_k}{2} \left(\left(\frac{\hat{k}_{t+2}}{\hat{k}_{t+1}} \right)^2 - 1 \right) \right) \right] \tag{15}$$

Equation (11) defines the marginal utility of consumption. Equation (12) determines equilibrium in the labor market, requiring that the marginal rate of substitution between leisure and consumption equals the marginal product of labor. Equation (13) determines the optimal capital utilization rate by equating the marginal cost of increased utilization due to higher depreciation to the marginal product of capital services. Equations (14) and (15) are the intertemporal Euler conditions determining the optimal portfolio allocation between bonds and capital. Finally, the resource constraint is

$$\hat{c}_t + \hat{x}_t + \hat{nx}_t = \hat{y}_t \tag{16}$$

where $\hat{nx}_t$ are (detrended) net exports, given by

$$\hat{nx}_t = \frac{\hat{d}_t}{g} - R_t^{-1}\hat{d}_{t+1} \qquad (17)$$

The household's debt position $\hat{d}_t$ is the economy's net foreign debt position in period t, and the trade balance, or net exports, are all resources not used for consumption and investment.

4 Data, Calibration and Solution Method

We carry out quantitative experiments by calibrating the model to Argentinean data from the sample 1980Q1-2008Q2. Appendix A provides more detail on data sources and transformations. In calibrating the model, the time unit is set to one quarter. Besides the parameters of the interest rate shock process, there are 17 additional parameters in the model. For 11 of those parameters $(\alpha, \beta, \delta, \eta, \zeta, \nu, \mu, \phi_k, \bar{R}, g, \sigma_a)$, we calibrate the values to match data moments on the basis of moments of the ergodic distribution implied by the nonlinear solution of the model. For 5 parameters $(\gamma, \psi, \omega, \rho_A, \rho)$, the values are harder to pin down directly from the data, and we chose values we believe are most common in the literature. The remaining parameter, φ, which determines the strength of the financial friction, is very important for the empirical success of the model as pointed out by Neumeyer and Perri (2005). For now we set $\varphi = 1$, such that the required working capital equals the total cost of intermediate good purchases, and we will devote Section 6.2 to a discussion of this assumption.

Preference parameters The moment utility and labor curvature parameters are fixed to $\gamma = 2$ and $\psi = 0.6$, which are the values used in Mendoza (1991), Aguiar and Gopinath (2007) and others. The discount factor β is set to match the average trade balance-to-GDP ratio in Argentina of 1.1% during 1981Q1 to 2008Q2. The implied average debt-to-GDP ratio is about 50%, or 12.5% in terms of annual GDP.[11] The labor weight ζ is important only for scaling and is set to normalize the

[11] The average net foreign asset-to-GDP ratio between 1980 and 2004 in the data of Lane and Milesi-Ferretti (2007) is −36.5%. In the model the only asset is a one-period bond and there is no default, which makes it impossible to

Table 3: Calibration.

a) Preferences	Symbol	Value	Target
Discount factor	β/g	0.9608	Trade balance to GDP ratio
Utility curvature	γ	2	Mendoza (1991), ...
Labor disutility weight	ζ	0.62	Normalized labor input
Inverse wage elasticity of labor supply	ψ	0.6	Mendoza (1991), ...
b) Technology			
Capital income share	α	0.38	Labor income share
Scaling parameter	ν	0.57	normalized GDP
Intermediate inputs weight	μ	0.44	IO table
Growth factor	g	1.0083	Average output growth
Production substitution elasticity	$1/(1-\rho)$	0.0001	Rotemberg and Woodford (1996)
Working capital requirement	φ	1	Aggregate working capital
Capital depreciation parameter 1	δ	-0.017	I-Y ratio, normalized utilization rate
Capital depreciation parameter 2	η	0.079	I-Y ratio, normalized utilization rate
Capital depreciation parameter 3	ω	0.44	Meza and Quintin (2007)
Capital adjustment cost	$\phi_k/2$	18.8	Relative investment volatility
Saving interest rate ceiling	$\bar{R}$	$1.02^{0.25}$	International riskless rate
c) Technology Shock Process			
Persistence of TFP shock	ρ_A	0.95	Neumeyer and Perri (2005)
Standard deviation of TFP shock	σ_A	0.0027	Output volatility
d) Interest Rate Shock Process			
See Table 1.			

average labor input to approximately one.

Technology parameters. The quarterly growth rate of the model economy $g-1$ is set to 0.83%, the average quarterly growth rate of real output in Argentina over the sample period, excluding the crisis drops after 1989Q1 and 2001Q2[12]. The parameter α is set to obtain a labor income share of 0.62 as in Mendoza (1991), Aguiar and Gopinath (2007) or Neumeyer and Perri (2005). We set the value of μ to match the 44.2% share of intermediate goods consumption in gross output, obtained from Argentina's 1997 input-output matrix.[13] We assume that there is very little possibility to substitute away from material inputs and set the elasticity of substitution to $1/(1-\rho)$ to a very low number as in Rotemberg and Woodford (1996). The depreciation parameters δ and η are set to normalize the rate of capital utilization and to match the average investment-output ratio in Argentina of 18.2%. The resulting quarterly depreciation rate is about 3.7% on average. The parameter ω, which determines the elasticity of the depreciation rate with respect to variations in capital utilization, is set to 0.44, the value in Meza and Quintin (2007).[14] The capital adjustment cost parameter ϕ_k is chosen to match the volatility of investment in the data. We posit an autoregressive process for the technology shock:

$$\ln(A_t) = \rho_A \ln(A_{t-1}) + \sigma_A \varepsilon_{A,t} \ , \ \varepsilon_{A,t} \sim \text{i.i.d } N(0,1) \tag{18}$$

We set $\rho_A = 0.95$, the same value as Neumeyer and Perri (2005), and choose σ_A to match the volatility of output.

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match both the average trade balance-to-GDP and debt-to-GDP ratios in the data at the same time.

[12]More precisely, to compute the average quarterly growth rate of output we excluded the rates corresponding to quarters 1989Q2 to 1990Q2 and 2001Q3 to 2004Q1. The beginning of the crises were dated using the estimated crisis probabilities from the regime switching model, in the same way as for the exercise in section 5.1. The end of each crisis was dated at the period at which output reached its pre-crisis level.

[13]The 1997 IO matrix is the only one publicly available for Argentina. We checked for another emerging country, South Korea, that the share of intermediate consumption in gross output is a relatively stable structural parameter (we used Korea's IO matrices for 1980, 1985, 1990, 1995, 2000 and 2003). For comparison, for the US Rotemberg and Woodford (1996) use a share of materials and energy costs of 52%, and Hornstein and Praschnik (1997) obtain a value of 45%.

[14]The value is not entirely comparable to Meza and Quintin (2007) because of slightly different parametrization of the depreciation function. Our specification allows us to match the investment-output ratio, but the depreciation elasticity is not constant and depends on u_t.

Real Interest Rates The interest rate process is the estimated regime switching model for Argentina, with parameters given in Table 1 and $\bar{R}$ set to $1.02^{0.25}$, the average real riskless rate on a US government 3-month Treasury-bill.

Numerical Solution We compute discrete approximations to the stochastic processes for technology and the interest rate. The technology process in (18) is approximated using the quadrature-based method of Tauchen and Hussey (1991) on a grid of 11 nodes. We approximate the Markov-switching process in (1) for the interest rate on a grid of 51 equidistant nodes. To facilitate the numerical solution procedure, our approximation of the interest rate process imposes that innovations are drawn from normal distributions that are truncated to ensure that the annualized net interest rate has a support bounded between 0% and 100%. To guarantee a satisfactory approximation to the Markov-switching model estimated from the data, we follow a simulated method of moments procedure: For given parameters $\Theta = [\nu(s_t), \sigma(s_t), vec(\Pi), \rho_r]$, we obtain the discrete approximation, simulate 52,000 observations and construct $\tilde{\Psi}(\Theta) = [\tilde{\nu}(s_t), \tilde{\sigma}(s_t), vec(\tilde{\Pi}), \tilde{\rho}_r, \tilde{\mu}_r, \tilde{\sigma}_r]'$ where $\tilde{\nu}(s_t)$, $\tilde{\sigma}(s_t)$, $vec(\tilde{\Pi})$ and $\tilde{\rho}_r$ are the Markov-switching model estimates and $\tilde{\mu}_r$ and $\tilde{\sigma}_r$ are the average unconditional sample mean and standard deviation over samples of the same length as the data. Finally, we find Θ that minimizes the loss function $\left[\tilde{\Psi}(\Theta) - \hat{\Psi}\right]' W \left[\tilde{\Psi}(\Theta) - \hat{\Psi}\right]$ where $\hat{\Psi}$ is a vector stacking the parameters estimated from the data and W is a diagonal weighting matrix containing the inverses of the variances of the parameter estimates.

Denoting the vector of state variables by $S_t = \left[\hat{k}_t, \hat{d}_t, R_t, A_t\right]$, we approximate the policy functions for the state variables $\hat{d}_{t+1} = d(S_t)$ and $\hat{k}_{t+1} = k(S_t)$ by piecewise linear functions over a grid, denoted by S, of $21 \times 21 \times 51 \times 2 \times 11 = 494,802$ nodes each and compute the approximate solution by iterating over the intertemporal Euler conditions, as suggested by Coleman (1990). The standard iteration procedure is generally slow and therefore we combine it with the method of endogenous gridpoints, proposed by Carrol (2006). More specifically, the algorithm is

Step 1 Obtain an initial guess $k_0(S)$ and $d_0(S)$ from a loglinear approximation around the deterministic steady state.

Step 2 Given the last guess $k_{j-1}(S)$ and $d_{j-1}(S)$, calculate $k'' = k_{j-1}(S)$, $d'' = d_{j-1}(S)$ and find c', y', h', u', λ' using the budget constraint and equations (10a), (11)-(13) and (16).

Step 3 Compute

$$e_1 = \frac{\beta}{g}\mathrm{E}\left[\lambda'|R,A\right]$$
$$e_2 = \frac{\beta}{g}\mathrm{E}\left[\lambda'\left(\alpha\frac{gy'}{k'} + 1 - \delta - \eta\frac{u'^{1+\omega}}{1+\omega} + \frac{\phi_k}{2}\left(\left(\frac{k''}{k'}\right)^2 - 1\right)\right)|R,A\right]$$

and solve for d and k, using

$$e_1 = \lambda R^{-1}$$
$$e_2 = \lambda\left(1 + \frac{\phi_k}{g}\left(\frac{k'}{k} - 1\right)\right)$$

as well equations (10a), (11)-(13) and (16).

Step 4 Using k', d' and k, d, R and A, interpolate to obtain $k'' = k_j(S)$ and $d'' = d_j(S)$.

Step 5 Repeat step 2 to 4 until convergence.

The algorithm is very efficient given the dimension of the state space, as there are no numerical rootfinding operations required: the lack of any wealth effects on labor supply implies that finding y, u and h is always straightforward.[15]

5 Results

The effects of technology and interest rate shocks in the standard small open economy model are relatively well understood. A positive shock to technology increases labor demand which, depending on the elasticity of labor supply, induces an increase in employment and production; see for

[15] Matlab programs are available from the authors.

instance Mendoza (1991) or Correia et al. (1995). The increase in current and future expected real income raises consumption, but as the productivity boom is transitory, households also respond by saving more. The increase in saving boosts investment in domestic capital and lowers debt to foreigners. On the other hand, households take advantage of higher productivity in domestic production and shift resources towards domestic investment, increasing foreign borrowing. The net effect on the trade balance depends on the model specifics and calibration. In our case with variable capital utilization and persistent technology shocks, the net effect is a positive comovement between output and the trade balance.

The main effect of an interest rate increase in the standard model is a shift away from domestic investment and a reduction of foreign debt. A reduction in wealth induces a drop of consumption, but there is generally little effect on output or labor supply. Because of the financial constraint in our model, however, there are additional effects through an increase in the financing distortion. Higher interest rates cause a rise in the relative cost of intermediate inputs which in turn lowers the marginal product of labor and capital. From equation (10b), it is clear that this additional effect is isomorphic to a negative technology shock. On balance, interest rate shocks yield comovement between output, investment and consumption, but unlike technology shocks, they also yield consumption responses that exceed those of output and a negative comovement between output and the trade balance. These effects are very similar to those in Neumeyer and Perri (2005), despite the difference in the modeling of the financial friction.

The dynamics in the model are not only governed by shocks to the levels of technology and interest rates, but also by shifts between tranquil and crisis regimes. According to our estimates of the Markov-switching model, a transition to the crisis regime does not only induce a rise in interest rates, but also a significant increase in the volatility of the interest rate shocks. As shown by Fernández-Villaverde et al. (2008), this volatility shift has important separate effects. There is an increase in the relative risk of foreign bonds, which induces households to reduce foreign indebtness. Repaying foreign debt requires a reduction in consumption and investment. This is especially true since the absence of wealth effects on labor supply prevents any increase in labor supply, and because the transition to a crisis means higher interest rates, which in turn lowers labor demand and output. With fewer resources available, and also a drop in the marginal product of capital because of the financing friction, consumption and investment will decrease significantly.

Depending on the relative importance of technology shocks versus interest rate shocks and the frequency of crises, consumption will be more volatile than output, and the trade balance and output will correlate negatively. Moreover, a crisis will be associated with large drops in output, consumption and investment, and a reversal in the trade balance. We now turn to the simulation results and compare a wide array of simulated moments to their empirical counterparts for Argentina.

5 .1 Benchmark Results

Tables 4 and 5 contain simulation results based on the benchmark calibration of the model. The first column of Table 4 contains the key business cycle statistics in the 1980Q1-2008Q2 sample of Argentinean quarterly data. The second column of Table 4 contains the corresponding moments in model simulated data, obtained by generating 1000 samples of the same size as the actual data, each with a burn-in of 1000 quarters. The table also reports the 10% and 90% quantiles of the simulated sample moments. The moments are for the year on year growth rates of output, consumption and investment as well as the trade balance to GDP ratio. To assess how sensitive our results are to the detrending method, Table 5 reports the moments when either a linear trend or the HP filter is used.

Consumption Volatility Recalling that the volatility of the growth rates of output and investment are matched by construction in the calibration, we first highlight the fact that the model is remarkably successful in producing a relative volatility of consumption that is in line with the data, regardless of the method of detrending. When using growth rates, the model moment averages 1.14, which is exactly the value in the data; when we use a linear trend and the HP-filter, the average sample relative volatility of consumption are 1.06 and 1.15, while the corresponding moments in the data are 1.07 and 1.17 respectively.

Countercyclical Trade Balance The model does very well in reproducing a strongly countercyclical trade balance: the correlation between output growth and the trade balance to GDP ratio is -0.53 in the model, whereas in the data it is -0.30 which is slightly above the 90% quantile. On the other hand, when computing the correlation with linearly detrended or HP-filtered output, the values in the data are higher: -0.76 and -0.67. The corresponding model moments average -0.51 and -0.52, respectively. Even though the precise number in the data is somewhat sensitive to the detrending method, the negative correlation produced by our model is much more pronounced than in Neumeyer and Perri (2005) when they assume independent interest rates and productivity shocks, and more in line with the data for Argentina.

Cyclicality of Interest Rates Regardless of the detrending method, the correlations between output and consumption on the one hand, and real interest rates on the other hand are all negative in the data. The correlation between investment and interest rates is close to zero when we use growth rates, but significantly negative for alternative detrending methods. The model is successful in reproducing the countercyclical properties of real interest rates, although it somewhat overstates the negative contemporaneous correlation between the real interest rate and output when using growth rates. However, the moment in the data lies within the 10% and 90% quantiles when using a linear trend or the HP-filter. Neumeyer and Perri (2005) show not only that interest rates are countercyclical in emerging markets, but also that interest rates lead the cycle. Figure 3 plots the cross-correlations between interest rates and output growth at different leads and lags for Argentinean data, as well as in the model. The figure indeed shows that interest rates correlate negatively with current and future output growth. Interestingly, the correlation between interest rates and lagged output growth becomes positive for lags greater than 2 quarters. The model accurately matches this inverse S-shape of the cross correlations between output growth and real interest rates.

Regardless of the detrending method, the average sample correlations for consumption and investment are somewhat below the corresponding moments in the data. The correlation for consumption in the data lies within the 10% and 90% quantiles of simulated sample moments when using growth rates and the HP-filter, while for investment the moments in the data are above the 90% quantile for the three detrending methods. Instead, the model performs very well in matching the correlation of the trade balance with interest rates. In the model, the sample average of the correlation is 0.67, very close to the 0.71 correlation in the data.

The Persistence of the Trade Balance Figure 4 depicts the autocorrelation function of the trade balance to GDP ratio, both in Argentinean data and the model generated samples. Garcia-Cicco, Pancrazi and Uribe (2006) show how the standard small open economy RBC model with only temporary and permanent technology shocks predicts a nearly flat autocorrelation function for the trade balance. From the empirical evidence in their paper, as well as from Figure 4, it is clear that this prediction is strongly counterfactual for Argentina: the autocorrelations are all significantly below one and they converge to zero relatively quickly as the number of lags increases. Figure 4 shows that the model with interest rate shocks is very successful in quantitatively replicating the autocorrelation function of the trade balance. The model autocorrelations are all smaller than one, somewhat smaller than in the data, and converge towards zero at approximately the same rate as in the data.

Sudden Stops Figure 5 plots the model response of output, consumption, investment and the trade balance to a shift from the tranquil regime to the crisis regime. In the graph, the country enters the crisis regime in period 1 and the responses are the averages over the simulated samples for crises that lasts at least 4 quarters. The grey area represents the area in which 80% of the simulated paths are situated. The straight line represents the trend growth path for output, consumption and investment and the unconditional mean for the trade balance to GDP ratio. For comparison, the graph also depicts the path of the variables for two Argentinean crises, which we date using the

Table 4: Simulation Results: Year on Year Growth Rates

		Data	Benchmark	No Crisis State	Tech Shocks Only
a) Standard Deviations					
Output (T)	$std(g_y)$	0.065	0.065 *(0.043,0.087)*	0.032	0.028
Consumption	$std(g_c)/std(g_y)$	1.14	1.14 *(0.97,1.31)*	0.86	0.75
Investment (T)	$std(g_x)/std(g_y)$	3.14	3.14 *(2.69,3.62)*	2.62	1.76
Trade balance to GDP	$std(nx/y)$	0.029	0.033 *(0.022,0.044)*	0.011	0.003
b) Cross-Correlations with g_y					
Consumption	$corr(g_c, g_y)$	0.94	0.94 *(0.91,0.97)*	0.96	0.99
Investment	$corr(g_x, g_y)$	0.92	0.94 *(0.91,0.96)*	0.94	0.99
Trade balance to GDP	$corr(nx/y, g_y)$	-0.30	-0.53^* *(-0.67,-0.37)*	-0.15	0.70
c) Cross-Correlations with R					
Output	$corr(g_y, R)$	-0.21	-0.45^* *(-0.60,-0.29)*	-0.28	0
Consumption	$corr(g_c, R)$	-0.26	-0.39 *(-0.54,-0.24)*	-0.36	0
Investment	$corr(g_x, R)$	-0.07	-0.31^* *(-0.47,-0.16)*	-0.32	0
Trade balance to GDP	$corr(nx/y, R)$	0.71	0.67 *(0.35,0.89)*	0.91	0

(T) denotes that the statistic was targeted in the calibration. Numbers in parenthesis are 10% and 90% quantiles. An asterisk in the second column denotes that the corresponding data moment does not lie within these quantiles.

Table 5: Simulation Results: Alternative Detrending Methods

		Linear Trend		HP-Filter	
		Data	Model	Data	Model
a) Standard Deviations					
Output	$std(\hat{y})$	0.086	0.068 *(0.040,0.099)*	0.042	0.041 *(0.027,0.056)*
Consumption	$std(\hat{c})/std(\hat{y})$	1.07	1.06 *(0.89,1.24)*	1.17	1.15 *(0.98,1.32)*
Investment	$std(\hat{x})/std(\hat{y})$	3.15	2.87 *(2.43,3.33)*	3.26	3.10 *(2.67,3.52)*
b) Cross-Correlations with $\hat{y}$					
Consumption	$corr(\hat{c},\hat{y})$	0.94	0.95 *(0.92,0.97)*	0.94	0.94 *(0.91,0.97)*
Investment	$corr(\hat{x},\hat{y})$	0.96	0.94 *(0.90,0.97)*	0.94	0.95 *(0.92,0.97)*
Trade balance to GDP	$corr(nx/y,\hat{y})$	-0.76	-0.51^* *(-0.74,-0.26)*	-0.67	-0.52 *(-0.71,0.15)*
c) Cross-Correlations with R					
Output	$corr(\hat{y},R)$	-0.65	-0.79 *(-0.93,-0.62)*	-0.55	-0.65 *(-0.80,-0.48)*
Consumption	$corr(\hat{c},R)$	-0.68	-0.84^* *(-0.95,-0.70)*	-0.54	-0.67 *(-0.84,-0.48)*
Investment	$corr(\hat{x},R)$	-0.63	-0.86^* *(-0.95,-0.72)*	-0.50	-0.68^* *(-0.84,-0.50)*

For the HP filter, a smoothing parameter of 1600 was used. Numbers in parenthesis are 10% and 90% quantiles. An asterisk denotes that the corresponding data moment does not lie within these quantiles.

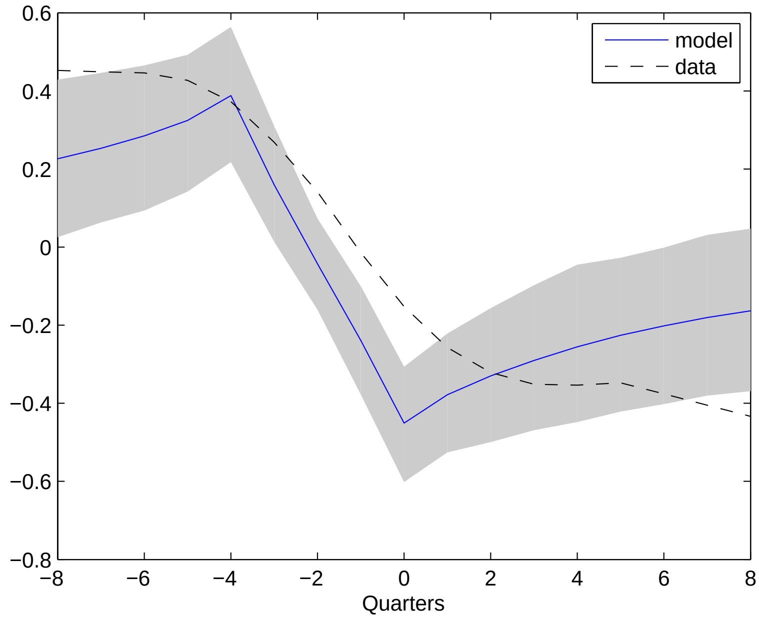

Figure 3: Cross-correlations between GDP growth at various leads and lags, and interest rates. The grey area indicates the region in which 80% of the simulated sample moments lie.

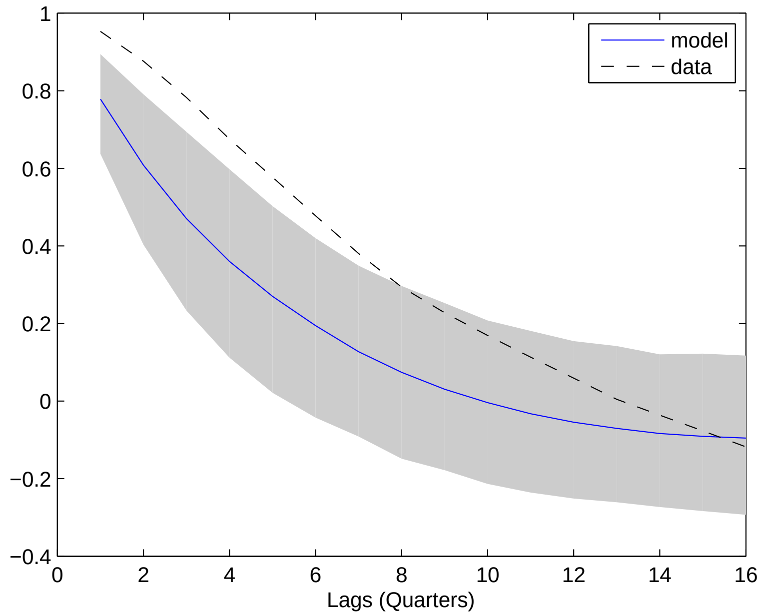

Figure 4: Autocorrelation function of the trade balance to GDP ratio. The grey area indicates the region in which 80% of the simulated sample moments lie.

estimated crisis probabilities from the regime switching model. The first crisis has a zero date of 1989Q1 after which, as is clear from Figure 1, the estimated crisis probabilities exceed one half for one year. The second crisis has a zero date of 2001Q2 after which the estimated crisis probabilities remain very high for several years.

On average, output falls 10% below trend in the model, consumption drops more than output and investment contracts by about one fourth a few periods after the transition. The average response of the trade balance shows every characteristic of a sudden stop, with the trade surplus quickly rising to 7% of GDP on average. One important feature of the responses is the persistence of the crisis induced dynamics: it takes very long for output, consumption and investment to return to their trend values. We believe this result can be reconciled with the finding of Aguiar and Gopinath (2007), who show that sudden stop dynamics can easily be replicated in the standard frictionless model by a permanent shock to technology. In contrast, however, the average response of the trade balance is much less persistent, which is in line with the arguments made by Garcia-Cicco et al. (2006). Judging by Argentina's experience in the 1989 and 2001 crises, the model produces crisis dynamics that are overall empirically plausible. One potential discrepancy is precisely the speed of the recovery: in both instances, output and especially investment have posted higher growth rates onwards from 2 or 3 years after the start of the crisis than those predicted on average by the model. This could be a failure of the model, but it could also be due to positive realizations of shocks.

5 .2 The Role of Crises: A Variance Decomposition

We now turn to the question on the importance of interest rates and the crisis regime for explaining the model's relative success in reproducing the salient features of the Argentinean business cycle. The last two columns in Table 4 contain the results of two simulation experiments aimed at quantifying the role of interest rate shocks for the volatility of the main macroeconomic aggregates. In the first experiment, we isolate the role of crises by computing the moments for 1000 samples in

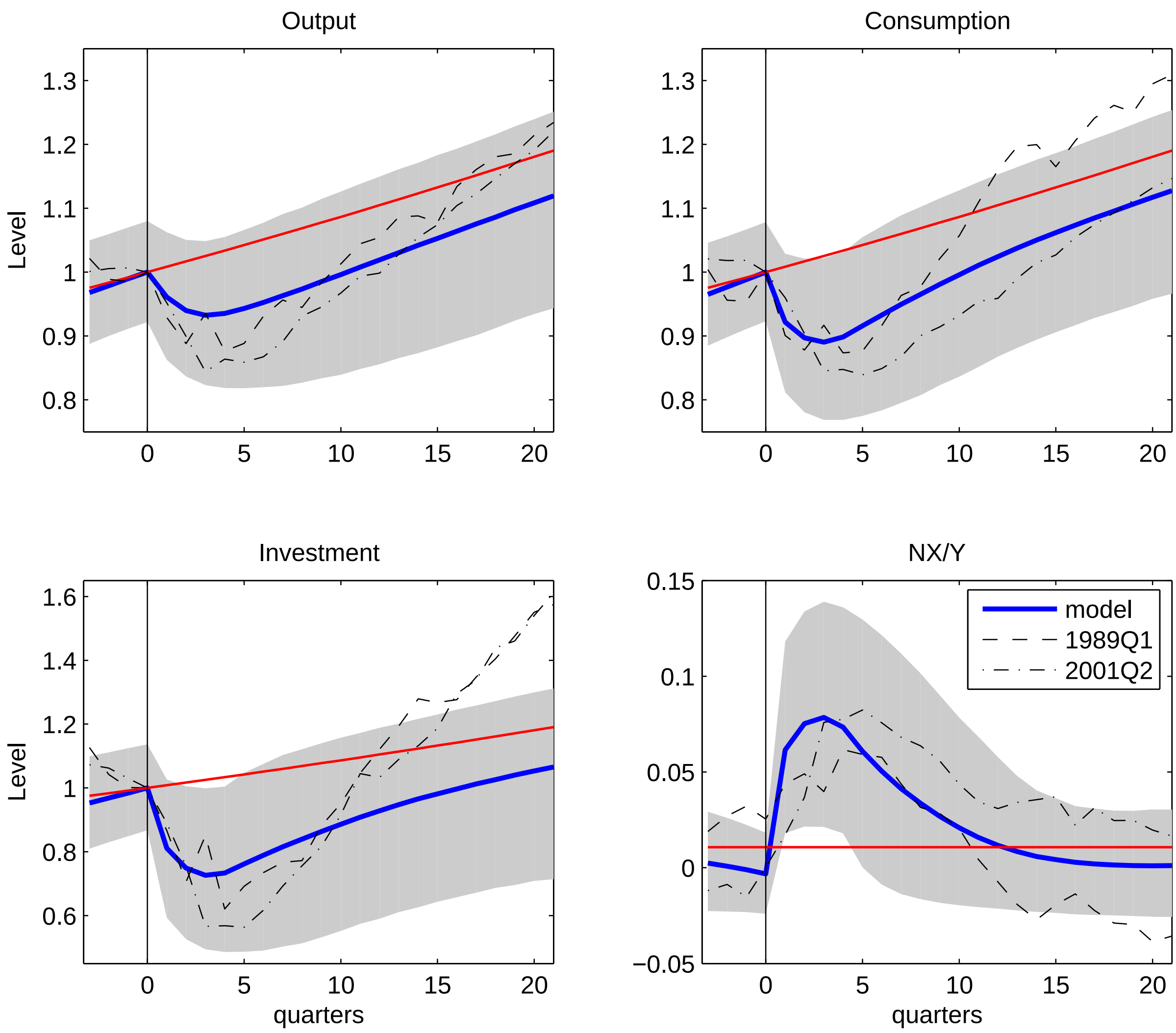

Figure 5: Response to a Crisis. Variables are in levels. For output, consumption and investment the period 0 value is normalized to one. The grey area indicates the region in which 80% of the simulated sample moments lie. The straight lines denote the trend values. Broken lines are Argentinean data with period 0 equal to 1989Q1 and 2001Q2 respectively.

which the crisis regime does not occur. When simulating the data, we use the same policy functions as before but force the realized interest rate process to be generated by an AR(1) process, the parameters of which are those of the estimated tranquil regime. In the second experiment, we compute the moments when the realization of the interest rate shocks is set to zero, such that there are only technology shocks. In both experiments, we do not change any of the parameter values of the model.

The first observation is that the presence of crises is the main reason why interest rate shocks are very important in accounting for business cycle volatility in Argentina. The standard deviation of output growth is 6.5% in the data. Without crises occurring, the standard deviation drops to 3.2%, or 51% lower than the value in the data. At the same time, removing the interest rate shocks altogether further reduces the standard deviation, but only by 0.4% or another 6%. Therefore, it is almost exclusively the crisis episodes that comprise the contribution of interest rate shocks to business cycle volatility. The numbers are identical when we use alternative detrending methods. For comparison, Neumeyer and Perri (2005) find that interest rate shocks account for about 30% of output volatility in Argentina, whereas Fernández-Villaverde et al. (2008) find only a 6% reduction in output volatility for Argentina when eliminating interest rate shocks. Our number is about 57%, which is significantly larger. One potential explanation for the discrepancy with Neumeyer and Perri (2005) is a quantitative difference in the strength of the financial friction. To a first approximation, a good measure of the role of the financing friction in explaining output volatility is the short-run elasticity of labor supply to the interest rate. In the benchmark calibration of Neumeyer and Perri (2005), a 1% increase in annual interest rates reduces labor input by approximately 0.25%. In our model, this elasticity is between -0.36% and -0.33% around the mean capital stock, depending on the level of the interest rate.[16] With labor input more responsive to changes in interest rates, it is no surprise that we obtain a larger role for interest rate shocks. However, the difference in elasticities is not because we have a stronger financial friction, but is because we allow

[16]The wage elasticity of labor supply and the output elasticity to labor in our calibration are identical to Neumeyer and Perri (2005), so these do not explain any difference.

for variable capacity utilization as an additional propagation mechanism. An increase in interest rates lowers the marginal product of capital, which lowers the rate of capacity utilization, which in turn lowers labor demand. When we consider regime dependent financial frictions, the elasticity of labor supply with respect to interest rates is between -0.29% and -0.26% in the crisis state and 0% otherwise. Instead, when we do not allow for variable capacity utilization, the elasticity is further reduced to between -0.22% and -0.18%. Therefore, according to this measure, the role of the financing friction in our model is smaller than in Neumeyer and Perri (2005) and it is varying capacity that in part explains our finding. We will turn to the role of varying capacity in more detail below. The other main reason for the discrepancy with Neumeyer and Perri (2005) lies in the nonlinear effects of regime switches and associated volatility shifts. Evidently, in a first order approximation to the model solution these effects are absent. In our simulations the shifts in interest rate volatility constitute an additional source of macroeconomic fluctuations. The simulations in Fernández-Villaverde et al. (2008) do incorporate the effects of both level and volatility changes of interest rates. However, their model has no financial friction, such that there is no strong effect of interest rates on capital and labor productivity. For this reason, they arrive at a much smaller role for interest rate shocks in explaining output volatility.

The second main result from our experiments is that the ability of the model to match the data also depends to a large extent on the presence of crises. Without crises, the relative volatility of consumption drops from 1.14 to 0.86, which is much lower than in the data. The correlation of the trade balance with output growth drops from -0.53 to -0.15, such that the trade balance is much less strongly countercyclical. The correlations of output, consumption and investment with interest rates become less negative, although they remain in line with the data. Finally, the correlation of the trade balance with the interest rate increases slightly without crises. When interest rate shocks are removed altogether, the relative volatility of consumption drops further to 0.75, and the trade balance becomes strongly procyclical with a correlation of 0.70. These findings are of course reminiscent of Neumeyer and Perri (2005), Garcia-Cicco et al. (2006) and others, who show that the standard RBC model with only technology shocks fails along these important dimensions. Our results suggest that while we need to incorporate financial frictions to bring the model closer to the data, quantitatively it is the combination with the occurrence of crises that matters most for the improved performance.

6 Two Additional Versions of the Model

To gain further insight into the quantitative results of the benchmark model, in this section we discuss the results for two alternative versions of the model. In the first, we eliminate the feature of a variable rate of capacity utilization, and impose a constant rate of utilization. In the second, we allow the strength of the financial friction, as embodied by the parameter φ, to be regime dependent.

6 .1 A Model without Variable Capacity Utilization

In the benchmark model, we found a large role for interest rate shocks as a source of business cycle fluctuations, and pointed to two main reasons: the additional amplification provided by a varying rate of capital utilization and the nature of the interest rate process. To assess the relative contribution of both features, we solve a different version of the model in which utilization is kept constant. The parameters are recalibrated to remain consistent with the moments of the ergodic contribution. The third column of Table 6 presents the results for this alternative model which, overall, still performs very well. Smaller amplification of interest rate shocks means technology shocks must account for a much larger share of output volatility than in the benchmark model. As a result, the model with fixed utilization yields lower consumption volatility: the relative standard deviation of consumption is now slightly lower than the value in the data, which is still comfortably within the 10%-90% quantiles. The smaller propagation of interest rate shocks weakens the countercyclical nature of interest rates and lowers the negative correlation of the trade balance with output relative to the benchmark model: both moments in the data now lie within the 10%-90%

quantiles of the simulated moments. Overall, the correlations of consumption, investment and the trade balance with output growth, as well as the correlations of all variables with interest rates are very much consistent with the data. When we conduct the same variance decomposition as before, the volatility of output growth is reduced by 18% when we remove the crises, as opposed to 51% in the benchmark model. Eliminating interest rate shocks altogether, the additional drop in output volatility is quantitatively very small. Therefore, the contribution of interest rate shocks to volatility depends importantly on the feature of varying capacity utilization. However, as in the benchmark model, it is still almost exclusively the presence of crises that comprises the effect of interest rate fluctuations. The main reason we include varying capacity in the benchmark model is the ability of the model to explain the response of the key variables to crises. As Meza and Quintin (2007), we find it very hard to explain the depth of the contraction in output and other variables during a crisis without a significant drop in utilization rates. The left panel of Figure 6 depicts the average path of output after entering a crisis lasting at least 4 quarters. The simulated drop in output is much smaller than in the benchmark model and the Argentinean crises of 1989 and 2001.

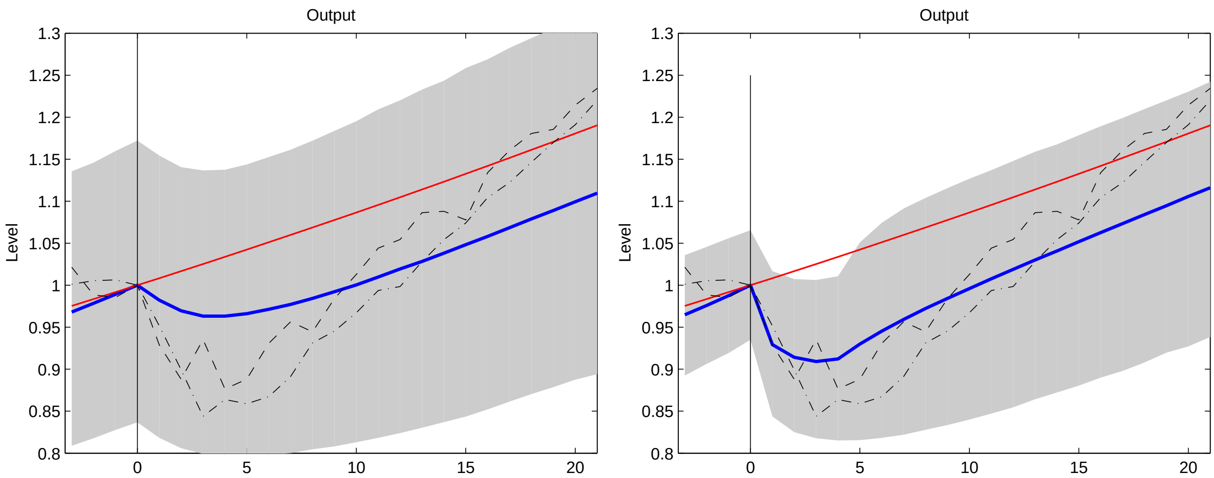

Figure 6: Response to a crisis of the output level. *Left Panel*: Model with fixed utilization; *Right Panel*: Model with regime dependent financial frictions. The period 0 value is normalized to one. The grey area indicates the region in which 80% of the simulated sample moments lie. Straight lines denote the trend values. Broken lines are Argentinean data with period 0 equal to 1989Q1 and 2001Q2 respectively.

Table 6: Simulation Results for two Alternative Models (Year on Year Growth Rates)

		Data	Benchmark	Fixed Utilization	Regime Dependent Friction
a) Standard Deviations					
Consumption	$std(g_c)/std(g_y)$	1.14	1.14	1.09	1.14
			(0.97,1.31)	*(0.94,1.26)*	*(0.98,1.31)*
Trade balance to GDP	$std(nx/y)$	0.029	0.034	0.042	0.035
			(0.022,0.044)	*(0.027,0.057)*	*(0.023,0.047)*
b) Cross-Correlations with g_y					
Consumption	$corr(g_c, g_y)$	0.94	0.94	0.91	0.94
			(0.91,0.97)	*(0.87,0.95)*	*(0.91,0.96)*
Investment	$corr(g_x, g_y)$	0.92	0.94	0.67^*	0.93
			(0.91,0.96)	*(0.56,0.78)*	*(0.90,0.96)*
Trade balance to GDP	$corr(nx/y, g_y)$	-0.30	-0.53^*	-0.33	-0.46
			(-0.66,-0.37)	*(-0.56,-0.09)*	*(-0.63,-0.26)*
c) Cross-Correlations with R					
Output	$corr(g_y, R)$	-0.21	-0.45^*	-0.38	-0.36
			(-0.60,-0.29)	*(-0.54,-0.19)*	*(-0.50,-0.19)*
Consumption	$corr(g_c, R)$	-0.26	-0.39	-0.37	-0.35
			(-0.54,-0.24)	*(-0.52,-0.20)*	*(-0.50,-0.20)*
Investment	$corr(g_x, R)$	-0.07	-0.31^*	-0.32^*	-0.27^*
			(-0.47,-0.16)	*(-0.47,-0.16)*	*(-0.41,-0.14)*
Trade balance to GDP	$corr(nx/y, R)$	0.71	0.67	0.63	0.73
			(0.35,0.89)	*(0.30,0.86)*	*(0.39,0.93)*

Numbers in parenthesis are 10% and 90% quantiles. An asterisk denotes that the corresponding data moment does not lie within these quantiles. For the model with fixed utilization, the only parameters that are different from the benchmark calibration in Table 3 are $\sigma_A = 0.0091$, $\phi_k/2 = 9$ and $\beta = 0.9624$. For the model with a regime dependent financial friction, the only two parameters that are different from the benchmark are $\eta = 0.080$ and $\beta = 0.9605$.

6 .2 A Model with Regime Dependent Financial Frictions

One potential criticism of the model is that in order to match the business cycle moments, the financial friction needs to be sufficiently strong. Indeed, just as in Neumeyer and Perri (2005), when we lower the value of the parameter φ, the model moves away from the data in terms of the high relative volatility of consumption, the right correlations with interest rates, and so on. Unfortunately, we do not have direct aggregate empirical measures of φ or the value of working capital. Nevertheless, some have argued that for these models to be successful, an implausible large stock of working capital or collateral is implied on average. In this section we address that criticism. Our earlier results clearly demonstrated that, with or without varying capacity utilization, it is the combination of financial frictions and crises that accounts for virtually all of the contribution of interest shocks to business cycle volatility. This suggests that what matters most quantitatively is the tightness of the financing constraint around crisis episodes, but not necessarily during tranquil times. To capture this idea, we modify the model by allowing the parameter φ to take on different values across the different regimes. More specifically, suppose that

$$\varphi(s_t) = \begin{cases} 0 & \text{if } s_t = T \\ 0.80 & \text{if } s_t = C \end{cases}$$

Given our estimated regime switching process for Argentina, this implies that, on average, in 77% of the observations in a given sample, there will be no evidence for any financial constraints. In the crisis regime, the parameter φ takes on a value of 0.80 which is lower than the value of one used in the benchmark calibration. We found that, when setting $\varphi(s_t = C) = 1$, the standard deviation of output growth in the simulations exceeded the value in the data, even when setting the standard deviation of the technology shock to zero. The reason is that movements in φ_t introduce a new source of fluctuations in measured factor productivity, as can be seen from equation (10b). The combined effect of movements in $\varphi(s_t)$ and the interest rate shocks yields excessive output volatility, which was a target statistic of the benchmark calibration. To make the results more comparable, we therefore chose to keep the volatility of technology shocks the same as in the benchmark calibration, and instead adjust the value of $\varphi(s_t = C) = 0.80$ to match the observed standard deviation of output growth. In order to be consistent with the same target statistics as the benchmark calibration, only very minor changes in the other parameter values were required (see the footnote in Table 6).

The last column in Table 6 displays the relevant business cycle moments of the model with a regime dependent financing friction. The results are remarkably similar to the benchmark model and in several respects even more in line with the Argentinean data. The relative standard deviation of consumption is identical to the benchmark value and the data counterpart. The trade balance remains strongly countercyclical, but the value of -0.46 is closer to the observed value of -0.30, which is now also within 10%-90% quantiles of the simulated moments. Since now interest rate shocks directly affect labor and capital productivity only in the crisis state, the cross correlations of output, consumption and investment are considerably lower. This brings these numbers closer to the values in the data, which except for investment, are now within the 10%-90% quantiles of the simulated moments. When we do the variance decomposition, removing the crises lowers the volatility of output by 59%, as opposed to 51% in the benchmark. Removing all interest rate shocks (as well as keeping $\varphi = 0$) does not further reduce output volatility significantly. The simulation results therefore reconfirm the key result of the benchmark model that it is crises episodes in combination with financing frictions that are key for the empirical success of the model. Outside of crises episodes, the presence of financing frictions is by and large inconsequential as movements in interest rates are far too small. As a result, a lack of evidence of sizeable financial constraints in a sample dominated by tranquil episodes does not automatically imply that these frictions are irrelevant for understanding emerging market fluctuations. Finally, the right panel of Figure 6 depicts the average path of output after entering a crisis lasting at least 4 quarters. Because of the simultaneous tightening of credit conditions, the simulated drop in output is more pronounced than in the benchmark model and quantitatively in line with the Argentinean crises of 1989 and 2001.

7 Conclusion

The real interest rate faced by many emerging market countries is a nonlinear stochastic process which can be characterized as alternating between a frequent low level/low volatility regime and an infrequent high level/high volatility regime. We incorporate these interest rate dynamics into a neoclassical small open economy model with a financial friction and variable capacity utilization for Argentina and find that the key empirical regularities of emerging market business cycles are well explained by exogenous fluctuations in interest rates; that the effects of interest rate movements are almost entirely due to the presence of the infrequent crisis regime; and that the ability of the model to match the data depends mainly on the presence of a sufficiently strong financial friction during the crisis regime, but not during tranquil times.

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A Data Appendix

We use data for Argentina from 1980Q1 to 2008Q2 for GDP, consumption, investment, exports and imports, and from 1983Q1 to 2008Q4 for the real interest rate. The data used are plotted in Figures 1 and 7. The series from the National Accounts are in constant prices (millions of pesos, prices of 1993). GDP is obtained from the Instituto Nacional de Estadisticas y Censos (INDEC) for the whole period. Consumption corresponds to private plus public consumption. Series on consumption, investment, imports and exports are obtained from INDEC for the period 1993Q1 to 2008Q2 and extended backwards until 1980Q1 by splicing with the data in Neumeyer and Perri (2005).

The real interest rates are constructed as in Neumeyer and Perri (2005). The nominal interest rates in US dollars correspond, each period (quarter or month), to the average daily yield for the 90-day U.S. T-bill in the secondary market plus the average J.P. Morgan EMBI+ Stripped Spread for each country. The real rates are obtained by deflating the nominal rate by the U.S. GDP Deflator expected inflation. Quarterly expected inflation is computed as the average of the actual GDP Deflator inflation in that quarter and in the three preceding ones. Monthly expected inflation is obtained by linearly interpolating the quarterly rate. From December 1993 onwards we use the country spreads calculated by J.P. Morgan. We extend the series for Argentina backwards at quarterly frequency until 1983Q1 by splicing with the data in Neumeyer and Perri (2005). For the last observation in our sample, 2008Q4, we used preliminary values. For the country spreads we used values available until November 11th, 2008, while for the U.S. T-bill yield we used values until November 13th, 2008. Regarding the U.S. GDP deflator inflation, we fitted an AR(1) model to its growth rate with data from 1980Q1 to 2008Q3 and projected the value for the last quarter: 2008Q4.

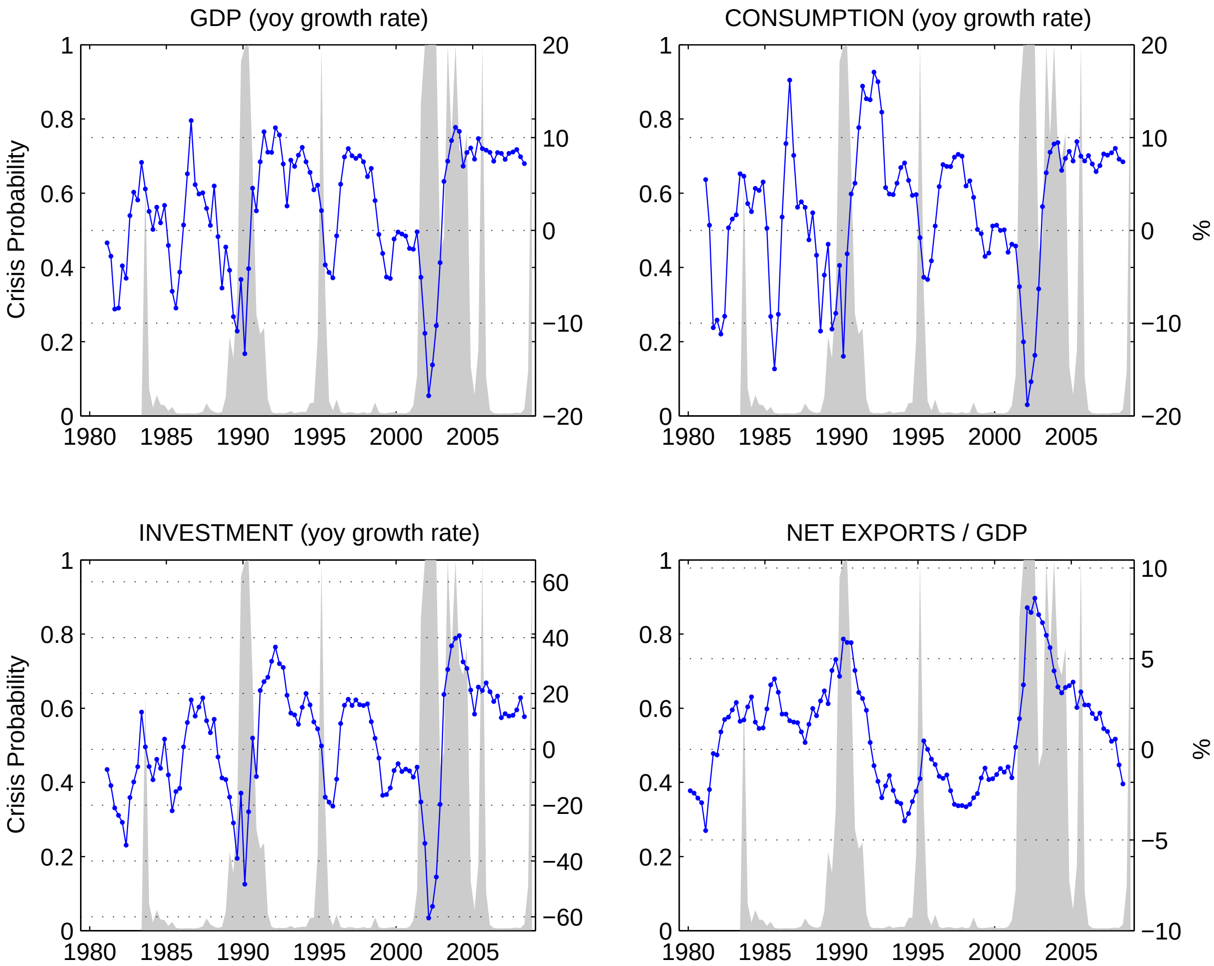

Figure 7: Main Macroeconomic Variables (1980Q1-2008Q2) and Estimated Crisis Probability (1983Q2-2008Q4) for Argentina.