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# Medium Term Business Cycles in Developing Countries<sup>1</sup>

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## **Abstract**

We build a two country asymmetric DSGE model with two features: (i) endogenous and slow diffusion of technologies from the developed to the developing country, and (ii) adjustment costs to investment flows. We calibrate the model to match the Mexico-U.S. trade and FDI flows. The model is able to explain the following stylized facts: (i) U.S. and Mexican output co-move more than consumption; (ii) U.S. shocks have a larger effect on Mexico than in the U.S.; (iii) U.S. business cycles lead over medium term fluctuations in Mexico; (iv) Mexican consumption is more volatile than output.

Keywords: Business Cycles in Developing Countries, Co-movement between Developed and Developing economies, Volatility, Extensive Margin of Trade, Product Life Cycle, FDI.

JEL Classification: E3, O3.

"Poor Mexico! So far from God and so close to the United States." Attributed to Dictator Porfirio Diaz, 1910.

Business cycle fluctuations in developed economies tend to have very strong effects on developing countries. Take for example the so-called Great Recession which started in the U.S. at the end of 2007. Between then and the first quarter of 2009, U.S. GDP had contracted by 2.2%. Mexico's economy was showing no sign of distress until the U.S. recession began. However, by the first quarter of 2009, Mexico's GDP had declined by 7.8%. Mexico was not the only country importantly affected by the U.S. recession. Many developing economies such as Malaysia, South Korea, the Philippines, and Taiwan suffered GDP contractions larger than the U.S. despite the initial soundness of their economy.<sup>1</sup>

These casual observations are hard to reconcile with standard international macro models. In these models, shocks are transmitted internationally because of their effect on the demand for exports.<sup>2</sup> As a result, foreign and domestic GDPs co-move positively. However, as shown below, the predicted effect of domestic shocks on foreign GDP is significantly smaller and more transitory than we see in the data.

The objective of this paper is twofold: our first goal is to develop a quantitative model capable of explaining the amplitude and persistence of the effect that U.S. shocks have on Mexico's macroeconomic variables. Our second goal is to use the model to provide an account of the drivers of business fluctuations in developing economies. In particular, we explore the relative contributions of domestic and U.S. shocks to Mexico's GDP fluctuations.

In Section 2, we present evidence that U.S. high frequency fluctuations affect Mexico's macroeconomic variables at medium term frequencies. In particular, HP-filtered U.S. GDP leads medium term fluctuations in both Mexico's GDP and embodied productivity. It is difficult to imagine that these protracted effects result from conventional propagation mechanisms in business cycle models. Rather, we show that, over the medium term, the range of technologies imported from the U.S. leads Mexico's productivity measures. Furthermore, the flow of

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<sup>1</sup>In a sample of countries, GDP declined as follows: Malaysia 7.8%, Philippines 12.1%, Singapore 7.4%, South Korea 3.3%, Taiwan 13.8%, Thailand 7.7%. In some of these Asian countries, high demand from China led to a recovery by the end of 2009 or the beginning of 2010.

<sup>2</sup>Unlike developed economies, as a result of the financial and banking regulations and practices imposed after the Asian crisis, the banking systems of most developing economies were very healthy before and during the Great Recession and did not contribute to its propagation (e.g. Zeti, 2002, Zamani, 2005, BIS, 2006).

new technologies exported from the U.S. to Mexico strongly co-moves with the U.S. business cycle. These findings suggest that U.S. business cycle fluctuations affect the speed of diffusion of technologies to Mexico and, through this channel, drive the medium term level of embodied productivity.

In Section 3, we develop our model. We consider a two-country (i.e. the U.S. and Mexico), asymmetric real business cycle model modified to allow for endogenous productivity, entry and adjustment costs to investment. We introduce entry to capture the strong counter-cyclicality of the relative price of capital. We introduce investment adjustment costs to be consistent with the micro evidence on investment frictions in Mexico (Gelos and Isgut, 2001; Iscan, 2000; Warner 1992, 1994). We incorporate endogenous productivity in order to provide a unified explanation for the comovements of U.S. GDP, and Mexico's GDP and relative price of capital over the high and medium term. Another reason for this decision is that many authors have questioned the importance of high frequency technology shocks and argued that short term fluctuations in the Solow residual reflect unmeasured input utilization and imperfect competition as opposed to true technology shifts (e.g. Burnside et al., 1995; Basu, 1996). Endogenous productivity, however, provides an avenue through which shocks may affect medium term fluctuations in productivity without having to rely on exogenous shifts in technology.

To endogenize productivity dynamics, we use a variation of Comin and Gertler's (2006) model of R&D and technology diffusion. We expand their framework to a two-country economy and allow for (slow) international diffusion of technologies and for foreign direct investment (FDI). Rotemberg (2003), for example, has argued that in modeling cyclical productivity dynamics it is important to take into account the diffusion lags. It is well known (e.g. Comin and Hobijn, 2010) that adoption lags are significantly longer in developing than in developed economies. Considering this, we calibrate our model to allow for realistic steady-state time lags between the creation of technologies in the U.S. and their diffusion to Mexico. At the same time, because the speed of diffusion varies endogenously with the cycle, the framework can produce pro-cyclical medium-term movements in Mexico's productivity in response to U.S. shocks.

The endogenous international diffusion of technologies in our framework differs from production sharing (e.g. Bergin et al., 2009; Burnstein et al., 2008) because it generates endogenous fluctuations in embodied productivity. A second difference with production sharing and with trade in varieties models (e.g. Ghironi and Melitz, 2005) is that, since in our model the diffusion of technologies involves a sunk investment, the range of exported technologies becomes a state variable. As we show in section 5, the dynamics of the stock of diffused technologies drive the

evolution of productivity over the medium term, and, through that channel, have important effects on the cyclical properties of Mexico's economy.

We introduce FDI because it permits the transfer of production of some goods to Mexico that are then exported to the U.S. As a result, a bilateral trade flow arises endogenously. Introducing FDI also allows us to capture realistically the nature of capital flows to developing countries, of which, since 1990, 70% have been in the form of FDI (Loayza and Servén, 2006).<sup>3</sup>

Section 4 presents some model simulations and considers how well the framework captures the broad data patterns. Overall, our model does a reasonably good job in characterizing the key features of short and medium term fluctuations in Mexico. In doing so, it sheds light on several important open questions in international macroeconomics. Unlike many RBC models (e.g. Backus, Kehoe and Kydland, 1992) our model generates a higher cross-country correlation of output than consumption. Our model matches the cross-country correlation in both output and consumption because what drives the short term cross-country co-movement in output is the pro-cyclical response of Mexico's investment to U.S. shocks. Mexico's consumption, on the other hand, does not respond much contemporaneously to U.S. shocks.

Our model also generates a large initial response of Mexico's GDP to U.S. shocks. Furthermore, the model reproduces the lead of U.S. short term fluctuations over medium term fluctuations in both Mexico's GDP and embodied productivity.

Two other features of the data that our model generate are the counter-cyclicalities of real interest rates and the current account in developing countries (e.g. Neumayer and Perri, 2005). Mexico's interest rates are counter-cyclical because domestic shocks cause counter-cyclical fluctuations in the relative price of capital that dominate the pro-cyclical response of the marginal product of capital. Since imports are used to produce new investment, the pro-cyclicalities of investment leads to a counter-cyclical current account.

Finally, the strong counter-cyclical response of domestic real interest rates to Mexican shocks permits our model to rationalize a regularity identified by Aguiar and Gopinath (2007). Namely, that consumption is more volatile than output in developing countries.

Section 4 also reports a decomposition of the volatility of Mexican short and medium term fluctuations. We find that approximately two thirds of the volatility of Mexico's output fluctuations is due to U.S. shocks. We reach this conclusion despite finding that Mexico's shocks are approximately 33% more volatile than U.S. shocks. Concluding remarks are in Section 5.

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<sup>3</sup>The FDI share is even larger when restricting attention to private capital flows and when focusing in Latin America and Asia.

# 1 The cyclicity of technology diffusion

In this section, we provide evidence on the role of technology diffusion in the propagation of U.S. business cycles to Mexico. Since we intend to identify the drivers of persistent fluctuations in the Mexican economy, we focus not only on conventional business cycle fluctuations but also on fluctuations at medium term frequencies. Following Comin and Gertler (2006), we define the *medium term cycle* as fluctuations with periods smaller than 50 years.<sup>4</sup> The medium term cycle can be decomposed into a *high frequency component* and a *medium term component*. The high frequency component captures fluctuations with periods smaller than 8 years while the medium term component captures fluctuations with periods between 8 and 50 years. We use a Hodrick-Prescott filter to isolate fluctuations at the high frequency. We isolate the medium term component and the medium term cycle using a band pass filter, which is basically a two-sided moving average filter, where the moving average depends on the frequencies of the data one tries to isolate. The medium term cycle roughly corresponds to the sum of the high and medium term components in the data.

In this section, we focus on three variables. We use GDP as a measure of output both in the U.S. and Mexico. We use the relative price of new capital in Mexico as measured by the investment deflator over the GDP deflator, a variable which has been used by Greenwood, Hercowitz and Krusell (2000) as a measure of the inverse of embodied productivity. Finally, we use the number of 6-digit SIC codes within durable manufacturing for which U.S. exports to Mexico are at least \$1 million. Broda and Weinstein (2006) use this variable to measure the range of technologies that diffuse internationally.

Our data is annual and covers the period 1990-2008. We restrict attention to this period for two reasons. First, the volume of U.S.-Mexico trade and FDI increased very significantly during this period, making the mechanisms emphasized by our model much more relevant than before. Second, after 1990, FDI became the most significant source of capital flows from developed to developing economies, making our model's assumptions about the nature of international capital flows most appropriate for this period.

Figure 1A plots the series of HP-filtered GDP in the U.S. and Mexico. Mexico's GDP is

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<sup>4</sup>Comin and Gertler (2006) show that there are approximately six medium term cycles in the U.S. over the postwar period. Most macroeconomic variables have a higher amplitude of fluctuations (i.e. a higher standard deviation) in the medium term component than in the high frequency component. Further, Comin and Gertler (2006) show that, despite the amplitude of the identified periods, fluctuations in the medium term component are statistically significant.

approximately twice as volatile as the U.S. The cross-country correlation in GDP is 0.43 and, despite the short length of the series, it is significant at the 10% level. Beyond this statistic, we can see that U.S. business fluctuations such as the internet-driven expansion during the second half of the 1990s, the burst of the dot-com bubble in 2001, the 2002-2007 expansion and the 2008 financial crisis are accompanied by similar fluctuations in Mexico. Arguably, none of the shocks that caused these U.S. fluctuations had a direct effect on the Mexican economy. Therefore, the co-movement between Mexico and U.S. GDP resulted from the international transmission of U.S. business cycles.<sup>5</sup>

The effects of U.S. business cycles on Mexico's GDP are very persistent and go beyond conventional business cycle frequencies. Figure 1B plots the medium term component of Mexico's GDP together with HP-filtered U.S. GDP. The lead-lag relationship between these variables can be most notably seen during the post 1995 expansion, the 2001 recession and the post-2001 expansion. Despite the severity of the effect of the Tequila crisis on the medium term component of Mexico's GDP, the latter strongly recovered with the U.S. post-1995 expansion. The Mexican medium term recovery lagged the U.S. boom by about two years. The end of Mexico's expansion also lagged the end of the U.S. expansion by one year. Finally, the post-2001 U.S. expansion also coincided with a boom in the medium term component of Mexico's GDP.

Table 1A formalizes these observations. The first row reports the correlation between HP-filtered U.S. GDP at various lags and the medium term component of Mexico's GDP. The contemporaneous correlation between these series is 0.28 and increases to 0.49 when U.S. GDP is lagged one year and to 0.53 when lagged two years. In the second row, we find a similar co-movement pattern between U.S. GDP and Mexico's embodied productivity. In particular, U.S. GDP fluctuations present a three-year lead over Mexico's medium term fluctuations in embodied productivity. Despite the short length of the series, these cross-correlation patterns are statistically significant.

What could be propagating U.S. business cycles to Mexico in such a persistent manner? Neoclassical investment dynamics are an unlikely answer since Nason and Cogley (1995) have shown that they cannot propagate shocks at these frequencies. Comin and Gertler (2006) argue that the endogenous technology improvements through R&D and technology adoption propagate U.S. shocks domestically over medium term frequencies. Could the international propagation we observe result from the international diffusion of technologies?

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<sup>5</sup>The only important Mexican shock over this period was the 1995 recession which, despite its virulence, was relatively short-lived.



Table 1B and 1C explore this hypothesis. Table 1B shows that the range of technologies that flow from the U.S. to Mexico is positively correlated with the U.S. business cycle. Table 1C shows that the range of durable manufacturing goods imported from the U.S. leads the medium term components of fluctuations in both Mexico's GDP and embodied productivity.

This evidence suggests that the return to exporting new investment goods from the U.S. to Mexico co-moves positively with the U.S. business cycle, and that fluctuations in the flow of new investment goods may be an important driver of medium term fluctuations in Mexico's productivity.

## 2 Model

We now develop a two-country model of medium term business fluctuations. We denote the countries by North,  $N$ , and South,  $S$ . The model is annual as opposed to quarterly because, as noted earlier, we are interested in capturing fluctuations over a longer horizon than is typically studied. To this end, we abstract from a number of factors that may be important to understand quarterly dynamics such as money and nominal rigidities.

Our model is a version of a conventional real business cycle model modified to allow for endogenous productivity and relative price of capital. To capture the short-term counter-cyclicality of the relative price of capital, we introduce two sectors and endogenous entry and exit. An alternative approach, with similar results, would be to allow for counter-cyclical markups as in Rotemberg and Woodford (1995).

We endogenize productivity by introducing endogenous R&D and international diffusion of technologies. Technologies are embodied in intermediate goods. Productivity depends on the number of intermediate goods available for production. As in the product cycle literature (e.g. Vernon, 1966; Wells, 1972; and Stokey, 1991), intermediate goods are invented in  $N$  as a result of R&D investments. After the producer incurs in a stochastic (sunk) investment, the good can be exported to  $S$  (i.e. it diffuses to  $S$ ). After a final stochastic investment, which we interpret as FDI, the production of the intermediate good is transferred to  $S$  and the good is exported from  $S$  to  $N$ .

Households are conventional. Exogenous shocks to the disutility from working drive fluctuations. Following Hall (1997) and others, we interpret these disturbances as a reduced form of more fundamental forces that affect the degree of rigidities in labor markets (i.e. wage markups).

We first describe the endogenous evolution of technology. We then discuss the production of capital and output and the household's problem. Finally, we characterize the complete equilibrium.

## 2.1 Technology

The sophistication of the production process in country  $c$  depends on the number of intermediate goods available for production,  $A_{ct}$ . There are three types of intermediate goods. There are  $A_t^l$  local intermediate goods that are only available for production in  $N$ . There are  $A_t^g$  global intermediate goods that have successfully diffused to  $S$ . These goods are produced in  $N$  and exported to  $S$ , and are available for production in both  $N$  and  $S$ . There are  $A_t^T$  intermediate goods whose production has been transferred to  $S$ . These goods are exported from  $S$  to  $N$  and are available for production in both  $N$  and  $S$ . The total number of intermediate goods in each country is therefore given by

$$A_{Nt} = A_t^l + A_t^g + A_t^T, \text{ and} \quad (1)$$

$$A_{St} = A_t^g + A_t^T. \quad (2)$$

Next, we present the conditions that characterize the technology dynamics in each economy.

*Creation of New Intermediate Goods.*— Innovators in  $N$  engage in R&D by investing final output to develop new intermediate goods. Each innovator,  $p$ , has access to the following technology:

$$A_{Nt+1}(p) - A_{Nt}(p) = \varphi_t S_t(p) - (1 - \phi)A_{Nt}(p), \quad (3)$$

where  $A_{Nt}(p)$  denotes her stock of invented goods,  $S_t(p)$  are her expenditures in R&D,  $(1 - \phi)$  is the per-period probability that an intermediate good becomes obsolete, and  $\varphi_t$  represents the productivity of the R&D technology, which is taken as given by the innovator.

We assume that  $\varphi_t$  depends on the aggregate stock of intermediate goods in  $N$ ,  $A_{Nt}$ , the medium term wholesale value of the capital stock,  $\bar{P}_{Nt}^k K_{Nt}$ , – to be defined below<sup>6</sup> – and aggregate R&D expenses,  $S_t$ , as follows:

$$\varphi_t = \chi A_{Nt} \left( \frac{S_t}{\bar{P}_{Nt}^k K_{Nt}} \right)^{\rho-1} (\bar{P}_{Nt}^k K_{Nt})^{-1}, \quad (4)$$

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<sup>6</sup>Roughly speaking it corresponds to the value of the capital stock priced at the cost of production faced by individual producers of investment goods.

with  $0 < \rho \leq 1$  and where  $\chi$  is a scale parameter. This formulation is borrowed from Comin and Gertler (2006) and allows us to calibrate the elasticity of innovations with respect to R&D expenditures to match the data. In addition, it ensures the existence of a balanced growth path without scale effects.

After developing a new technology, the innovator is granted a patent that protects her rights to the monopolistic rents from selling the good that embodies it. These rents have a market value of  $v_t$ . In equilibrium, agents engage in R&D activities until the cost of developing a new intermediate good (LHS) equalizes its expected market value (RHS):

$$1/\varphi_t = \phi \mathbb{E}_t [\Lambda_{Nt+1} v_{t+1}], \quad (5)$$

where  $\Lambda_{Nt+1}$  is the innovator's stochastic discount factor for returns between  $t$  and  $t + 1$ .

Equation (5) strongly hints at how the framework generates pro-cyclical R&D. When  $N$  experiences a recession, the expected value of a new local intermediate good,  $\mathbb{E}_t v_{t+1}$ , declines. That is, since the profit flow for local goods declines, the benefit to creating new varieties of intermediate goods goes down. R&D spending will decline in response.

*International Diffusion.* – Producers of local intermediate goods have the option of engaging in a stochastic investment that, if successful, permits the diffusion of the intermediate good to  $S$ . The probability of succeeding in this investment is  $\lambda(\Gamma_t^g x_t^g)$ , where the function  $\lambda(\cdot)$  satisfies  $\lambda' > 0$ ,  $\lambda'' < 0$ ,  $x_t^g$  is the amount of final output invested, and  $\Gamma_t^g$  is a scaling factor.<sup>7</sup> We model  $\Gamma_t^g$  so that it adjusts slowly to guarantee balanced growth.

$$\Gamma_t^g = \frac{b^g}{(\bar{P}_{Nt}^k K_{Nt} / A_t^l)}, \quad \text{with the constant } b^g > 0. \quad (6)$$

The market value of a local intermediate good reflects both the present discounted value of local profits as well as the value of the option to become global as shown in the following Bellman equation:

$$v_t = \max_{x_t^g} \pi_t - x_t^g + \phi \mathbb{E}_t \left\{ \Lambda_{Nt+1} \left[ \lambda(\Gamma_t^g x_t^g) v_{t+1}^g + (1 - \lambda(\Gamma_t^g x_t^g)) v_{t+1} \right] \right\}, \quad (7)$$

where  $\pi_t$  denotes the per period profits of a local intermediate goods producer and  $v^g$  is the market value of a global intermediate good. At any given period,  $v^g$  is greater than  $v$  because

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<sup>7</sup>We do not have to take a strong stand on who engages in the investments in exporting and in transferring the production of the goods to  $S$ . For expositional purposes, we assume it is the innovator, but the model is isomorphic to one where he auctions the patent and somebody else is in charge of making these investments afterwards.

global goods producers enjoy a profit stream from selling goods at both  $N$  and  $S$ . Shipping the goods internationally involves an iceberg transport cost. In particular,  $1/\psi$  (with  $\psi < 1$ ) units of the good need to be shipped so that one unit arrives.

The optimal investment,  $x^g$ , equalizes, at the margin, the cost and the expected benefits of exporting the intermediate good to  $S$  as shown in the following first order condition:

$$1 = \overbrace{\Gamma_t^g \lambda'(\Gamma_t^g x_t^g)}^{\text{Mg. } \Delta \text{ in } \lambda^g} \overbrace{\mathbb{E}_t \{ \phi \Lambda_{Nt+1} (v_{t+1}^g - v_t) \}}^{\Delta \text{ in value}}. \quad (8)$$

The marginal cost of investing one unit of output in exporting the good (LHS) is 1, while the expected marginal benefit is equal to the associated increase in the probability of international diffusion times the discounted gain from making the intermediate good global.

It is now easy to see why expenditures in the international diffusion of technologies will move procyclically. During recessions, the value of a global intermediate good declines by more than the value of a local intermediate good (i.e.  $\mathbb{E}_t (v_{t+1}^g - v_t)$  declines). In this case,  $x_t^g$  will decline since the return to investing in exporting intermediate goods goes down. The reverse, of course, will happen during booms.

The value of an intermediate good,  $v_t^g$ , is given by

$$v_t^g = \max_{x_t^T} \pi_t^g - e_t x_t^T + \phi \mathbb{E}_t \{ \Lambda_{Nt+1} [ \lambda(\Gamma_t^T x_t^T) v_{t+1}^T + (1 - \lambda(\Gamma_t^T x_t^T)) v_{t+1}^g ] \}, \quad (9)$$

where  $\pi_t^g$  denotes the per period profits of a global intermediate goods producer,  $x_t^T$  is the number of units of country  $S$ 's final output spent in transferring the production of the intermediate good to  $S$ ,  $\lambda(\Gamma_t^T x_t^T)$  is the associated probability of successfully completing this foreign direct investment, where the function  $\lambda(\cdot)$  satisfies  $\lambda' > 0$ ,  $\lambda'' < 0$ ,  $e_t$  is the exchange rate (dollars per peso),  $v^T$  is the market value of the company that produces a transferred intermediate good, and  $\Gamma_t^T$  is a scaling factor, taken as exogenous by the innovator and equal to

$$\Gamma_t^T = \frac{b^T}{(\bar{P}_{Nt}^k K_{Nt} / A_t^g)}. \quad (10)$$

*Foreign Direct Investment.*— The South has comparative advantage in assembling manufacturing goods (e.g. Iyer, 2005). In particular, it takes one unit of final output to produce a unit of intermediate good in  $N$ , while if the intermediate good is assembled in  $S$ , it only takes  $1/\xi (< 1)$  units of country  $S$  output. This cost advantage results in higher profit flows from

transferred global intermediate goods than from global intermediate goods (i.e.  $\pi_t^T > \pi_t^g$ ), and induces producers of global intermediate goods to transfer the production of intermediate goods from  $N$  to  $S$ .

The optimal intensity of FDI,  $x_t^T$ , equalizes the private marginal costs and expected benefits of transferring the production to  $S$ . The marginal cost is  $e_t$ , while the expected marginal benefit is the increase in the probability of succeeding in the FDI times the discounted gain from transferring the production of the intermediate good to  $S$ . Formally,

$$e_t = \overbrace{R_{Nt+1}^{-1} \phi}^{\text{discounting}} \overbrace{\Gamma_t^T \lambda'(\Gamma_t^T x_t^T)}^{\text{Mg. } \Delta \text{ in } \lambda^T} \overbrace{\mathbb{E}_t(v_{t+1}^T - v_{t+1}^g)}^{\Delta \text{ in value}}, \quad (11)$$

where  $v_t^T$  is defined by the following Bellman equation:

$$v_t^T = \pi_t^T + R_{Nt+1}^{-1} \phi E_t v_{t+1}^T. \quad (12)$$

## 2.2 Production

*Investment.*— Investment is produced in two stages. In a first stage, a continuum of  $N_{ct}^K$  differentiated capital goods producers combine the intermediate goods available in the country to manufacture their capital goods. In a second stage, the differentiated capital goods are used to produce competitively new investment.

Specifically, let  $I_{ct}(r)$  be the amount of differentiated capital produced by producer  $r$ , and let  $I_{ct}^r(s)$  be the amount of intermediate good  $s$  she demands. Then we can express the amount of differentiated capital she produces by

$$I_{ct}(r) = \left( \int_0^{A_{ct}} I_{ct}^r(s)^{\frac{1}{\theta}} ds \right)^{\theta}, \text{ with } \theta > 1. \quad (13)$$

Investment,  $J_{ct}$ , is produced competitively by combining these  $N_{ct}^k$  differentiated capital outputs as follows:

$$J_{ct} = \left( \int_0^{N_{ct}^K} I_{ct}(r)^{\frac{1}{\mu^K}} dr \right)^{\mu^K}, \text{ with } \mu^K > 1. \quad (14)$$

Each differentiated capital goods producer holds some market power that enables her to earn monopolistic rents from selling her capital good. To be operative, capital goods producers need to incur in an operating cost,  $o_{ct}^k$ . We assume that  $o_{ct}^k$  is proportional to the sophistication of the economy as measured by the wholesale value of the capital stock:

$$o_{ct}^k = b_c^k \bar{P}_{ct}^K K_{ct}, \quad (15)$$

where  $b_c^k$  is a positive constant.

Higher rents lead more capital goods producers to enter the production of differentiated capital goods. Free entry implies that, in equilibrium, the level of  $N_{ct}^k$  is such that the operating profits (LHS) equal the operating costs (RHS):

$$\frac{\mu^k - 1}{\mu^k} P_{ct}^K(j) I_{ct}(j) = b_c^k \bar{P}_{ct}^K K_{ct}, \quad (16)$$

where  $P_{ct}^K(j)$  is the price charged by the producer of the  $j^{th}$  differentiated capital good in country  $c$ .

Observe from (13) and (14) that there are efficiency gains in producing new capital from increasing the number of intermediate inputs,  $A_{ct}$ , and of differentiated capital producers,  $N_{ct}^k$ . As we shall see, these efficiency gains are responsible for the counter-cyclical price of new capital,  $P_{ct}^K$ .<sup>8</sup>

*Output.*— For symmetry with the capital sector, we assume that final output,  $Y_{ct}$ , is produced in two stages. At the first stage, each of  $N_{ct}$  differentiated output producers, indexed by  $j$ , combines capital,  $K_{cjt}$ , labor,  $L_{cjt}$ , and energy,  $E_{cjt}$ , to produce its differentiated output,  $Y_{ct}(j)$ , with the following Cobb-Douglas technology:

$$Y_{ct}(j) = (1 + g)^t (U_{cjt} K_{cjt})^\alpha E_{cjt}^\eta (L_{cjt})^{1-\eta-\alpha}, \quad (17)$$

where  $g$  is the exogenous growth rate of disembodied productivity,<sup>9</sup> and  $U$  denotes the intensity of utilization of capital. Factor markets (i.e. labor, energy and capital) are perfectly competitive.

At the second stage, gross output,  $Y_{ct}$ , is produced competitively by aggregating the  $N_{ct}$  differentiated final goods as follows:

$$Y_{ct} = \left[ \int_0^{N_{ct}} Y_{ct}(j)^{\frac{1}{\mu}} dj \right]^\mu, \text{ with } \mu > 1. \quad (18)$$

Differentiated final goods producers need to incur an operating cost,  $o_{ct}$ , to remain operative. We assume,

$$o_{ct} = b_c \bar{P}_{ct}^K K_{ct}. \quad (19)$$

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<sup>8</sup>An alternative formulation with similar implications for the high frequency fluctuations in the relative price of capital would be to introduce counter-cyclical price markups.

<sup>9</sup>For simplicity, we assume that it is exogenous. It is quite straightforward to endogenize it as shown in Comin and Gertler (2006).

Free entry equalizes the per period operating profits to the overhead costs determining the number of final goods firms  $N_{ct}$ .

$$\frac{\mu - 1}{\mu} P_{ct}(j) Y_{ct}(j) = b_c \bar{P}_{ct}^K K_{ct} \quad (20)$$

*Energy Endowments.*— Oil represents a significant share of Mexican exports to the U.S. To account for this in the calibration of the model, we assume that the government in country  $S$  is endowed with  $E_{St}^e$  units of energy. Let  $E_{ct}$  denote the aggregate consumption of energy in country  $c$ . Country  $N$  imports  $E_t^x$  units of energy from country  $S$ , and buys the rest of its energy needs,  $E_t^w$ , from the rest of the world. The energy consumption in each country satisfies the following identities:

$$E_{St} = E_{St}^e - E_t^x; \quad (21)$$

$$E_{Nt} = E_t^w + E_t^x. \quad (22)$$

For simplicity, we assume that the price of energy,  $P^E$ , is fixed (in terms of  $N$ 's currency) and that  $S$ 's endowment of energy grows at the steady state growth rate of output.

## 2.3 Households

*Households.*— In each country, there is a representative household that consumes, supplies labor and saves. It may save by either accumulating capital or lending to innovators. The household also has equity claims in all monopolistically competitive firms in the country. It makes one period loans to innovators and also rents capital that it has accumulated directly to firms. Physical capital does not flow across countries. Further, there is no other form of international lending and borrowing. This implies that  $N$ 's FDI in  $S$  is the only item in  $S$ 's financial account.

Let  $C_{ct}$  be consumption and  $\mu_{ct}^w$  a shock to the disutility of working. Then the household maximizes its present discounted utility as given by the following expression:

$$\mathbb{E}_t \sum_{i=0}^{\infty} \beta^{t+i} \left[ \ln C_{ct} - \mu_{ct}^w \frac{(L_{ct})^{\zeta+1}}{\zeta + 1} \right], \quad (23)$$

subject to the budget constraint

$$C_{ct} = \omega_{ct} L_{ct} + \Pi_{ct} + D_{ct} K_{ct} - P_{ct}^k J_{ct} + R_{ct} B_{ct} - B_{ct+1} - T_{ct} \quad (24)$$

where  $\Pi_{ct}$  reflects the profits of intermediate goods producers paid out fully as dividends to households,  $D_{ct}$  denotes the rental rate of capital,  $J_{ct}$  is investment in new capital,  $B_{ct}$  is the

total loans the household makes at  $t - 1$  that are payable at  $t$ , and  $T_{ct}$  reflects lump sum taxes.  $R_{ct}$  is the (possibly state-contingent) payoff on the loans.

The household's stock of capital evolves as follows:

$$K_{ct+1} = (1 - \delta(U_{ct}))K_{ct} + J_{ct}\left(1 - \xi_c\left(\frac{J_{ct}}{J_{ct-1}(1 + g_K)}\right)\right), \quad (25)$$

where  $g_K$  denotes the steady state growth rate of capital.  $\delta(U_{ct})$  is the depreciation rate which is increasing and convex in the utilization rate as in Greenwood, Hercowitz and Huffman (1988). The convex function  $\xi_c(\cdot)$  represents the adjustment costs that are incurred when the level of investment changes over time. We assume that  $\xi_c(1) = 0$ ,  $\xi'_c(1) = 0$ , so that there are no adjustment costs in the steady state.<sup>10</sup> Note also that the function  $\xi_c(\cdot)$  is indexed by  $c$  reflecting international asymmetries in the magnitude of adjustment costs.

The household's decision problem is simply to choose consumption, labor supply, capital and bonds to maximize equation (23) subject to (24) and (25).

*Government.*— Government spending is financed every period with lump sum taxes and the revenues from oil:

$$G_{ct} = T_{ct} + P^E E_{ct}^e. \quad (26)$$

### 3 Symmetric equilibrium

The economy has a symmetric sequence of markets equilibrium. The endogenous state variables are the aggregate capital stocks in each country,  $K_{ct}$ , and the stocks of local,  $A_t^l$ , global,  $A_t^g$ , and transferred,  $A_t^T$ , intermediate goods. The following system of equations characterizes the equilibrium.

*Resource Constraints and Aggregate Production.*— The uses of output in each country are divided into consumption, government spending, overhead costs, production of intermediate goods used in the production of new capital and investments in the creation, diffusion and transfer of intermediate goods:

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<sup>10</sup>This is the specification for the investment adjustment costs used in Christiano, Eichenbaum and Evans (2005), Jaimovich and Rebelo (2008), and Comin, Gertler and Santacreu (2009).



$$\begin{aligned}
Y_{Nt} = & C_{Nt} + S_t + x_t^g A_t^l + \overbrace{\frac{\mu-1}{\mu} Y_{Nt} + \frac{\mu^K-1}{\mu^K} P_{Nt}^K J_{Nt}}^{\text{overhead costs}} + G_{Nt} \\
& + \underbrace{\frac{P_{Nt}^K J_{Nt}}{\mu^K \theta a_{Nt}} \left(1 + \frac{A_t^g}{A_t^l}\right)}_{\text{intermediates sold to N}} + \underbrace{e_t \frac{P_{St}^K J_{St}}{\mu^K \theta a_{St}} \frac{A_t^g}{A_t^T} \left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}}}_{\text{intermediates sold to S}} \\
& \underbrace{\hspace{10em}}_{\text{production of investment goods}}
\end{aligned} \tag{27}$$

$$\begin{aligned}
Y_{St} = & C_{St} + x_{St}^T A_t^g + \overbrace{\frac{\mu-1}{\mu} Y_{St} + \frac{\mu^K-1}{\mu^K} P_{St}^K J_{St}}^{\text{overhead costs}} + G_{St} \\
& + \underbrace{\frac{P_{Nt}^K J_{Nt}}{e_t \mu^K \theta a_{Nt}} \frac{A_t^T}{A_t^l} \left(\frac{\psi \xi}{e_t}\right)^{\frac{1}{\theta-1}}}_{\text{intermediates sold to N}} + \underbrace{\frac{P_{St}^K J_{St}}{\mu^K \theta a_{St}} \xi^{\frac{1}{\theta-1}}}_{\text{intermediates sold to S}} \\
& \underbrace{\hspace{10em}}_{\text{production of investment goods}}
\end{aligned} \tag{28}$$

The output produced in each country is given by

$$Y_{ct} = (1+g)^t N_{ct}^{\mu-1} (U_{ct} K_{ct})^\alpha E_{cjt}^\eta (L_{cjt})^{1-\eta-\alpha}, \tag{29}$$

where the term  $N_{ct}^{\mu-1}$  reflects the efficiency gains from diversity.

*Factor Markets.*— The labor market in each country satisfies the requirement that the marginal product of labor equals the product of the price markup and the household's marginal rate of substitution between leisure and consumption:

$$(1-\alpha) \frac{Y_{ct}}{L_{ct}} = \mu \mu_{ct}^w L_{ct}^\zeta C_{ct}. \tag{30}$$

The equilibrium conditions for capital, the utilization rate and energy are, respectively:

$$\alpha \frac{Y_{ct}}{K_{ct}} = \mu [D_{ct} + \delta(U_{ct}) P_{ct}^I] \tag{31}$$

$$\alpha \frac{Y_{ct}}{U_{ct}} = \mu \delta'(U_{ct}) P_{ct}^I K_{ct} \tag{32}$$

$$\eta \frac{Y_{ct}}{E_{ct}} = \mu P_{ct}^E, \tag{33}$$

where  $P_{Nt}^E = P^E$  and  $P_{St}^E = P^E/e_t$ .

*Optimal Investment.*– The stock of capital evolves according to the following law of motion:

$$K_{ct+1} = (1 - \delta(U_{ct}))K_{ct} + J_{ct}(1 - \xi_c \left( \frac{J_{ct}}{J_{ct-1}(1 + g_K)} \right)) \quad (34)$$

The adjustment costs introduce a wedge between the price of new capital ( $P_{ct}^K$ ) and the price of installed capital ( $P_{ct}^I$ ) when the flow of real investment deviates from the steady state level. In particular, a reduction in investment raises the price of installed capital because the adjustment costs in (34) induce a higher cost of investment in the future. As a result, the optimal investment dynamics (35) tend to smooth out investment flows:

$$\begin{aligned} P_{ct}^K &= P_{ct}^I \left[ 1 - \xi_c \left( \frac{J_{ct}}{J_{ct-1}(1 + g_K)} \right) - \xi'_c \left( \frac{J_{ct}}{J_{ct-1}(1 + g_K)} \right) \frac{J_{ct}}{J_{ct-1}(1 + g_K)} \right] \\ &+ \mathbb{E}_t \left[ P_{ct+1}^I \beta \Lambda_{c,t+1} \xi'_c \left( \frac{J_{ct+1}}{J_{ct}(1 + g_K)} \right) \left( \frac{J_{ct+1}}{J_{ct}(1 + g_K)} \right)^2 \right]. \end{aligned} \quad (35)$$

*Consumption/Savings.*– We can express the intertemporal Euler equation as

$$\mathbb{E}_t \left\{ \beta \Lambda_{c,t+1} \frac{\left[ \alpha \frac{Y_{ct}}{\mu K_{ct+1}} + (1 - \delta(U_{ct+1})) P_{ct+1}^I \right]}{P_{ct}^I} \right\} = 1, \quad (36)$$

where

$$\Lambda_{c,t+1} = C_{ct}/C_{ct+1}. \quad (37)$$

Arbitrage between acquisition of capital and loans to innovators and exporters implies

$$\mathbb{E}_t \{ \beta \Lambda_{c,t+1} R_{t+1} \} = \mathbb{E}_t \left\{ \beta \Lambda_{c,t+1} \frac{\left[ \alpha \frac{Y_{ct}}{\mu K_{ct+1}} + (1 - \delta(U_{ct+1})) P_{ct+1}^I \right]}{P_{ct}^I} \right\}. \quad (38)$$

*Free Entry.*– Free entry by final goods producers in each sector yields the following relationship between operating profits and the number of final good producers:

$$\frac{\mu - 1}{\mu} \frac{Y_{ct}}{N_{ct}} = b_c \bar{P}_{ct}^K K_{ct}; \quad (39)$$

$$\frac{\mu^K - 1}{\mu^K} \frac{P_{ct}^K J_{ct}}{N_{ct}^K} = b_c^k \bar{P}_{ct}^K K_{ct}. \quad (40)$$

*Profits, Market Value of Intermediates and Optimal Technology Diffusion and FDI.*– The profits accrued by local intermediate good producers depend only on the demand conditions in  $N$ , while the profits of global and transferred intermediate goods depends also on the demand in  $S$ . Specifically, they are given by

$$\pi_t = \left(1 - \frac{1}{\theta}\right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} \quad (41)$$

$$\pi_t^g = \left(1 - \frac{1}{\theta}\right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} + \left(1 - \frac{1}{\theta}\right) e_t \frac{P_{St}^K J_{St}}{\mu_k a_{St} A_t^T} \left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}}, \quad (42)$$

$$\pi_t^T = \left(1 - \frac{1}{\theta}\right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} \left(\frac{\psi \xi}{e_t}\right)^{\frac{1}{\theta-1}} + \left(1 - \frac{1}{\theta}\right) e_t \frac{P_{St}^K J_{St}}{\mu_k a_{St} A_t^T}, \quad (43)$$

where  $a_{Nt}$  is the ratio of the effective number of intermediate goods in  $N$  relative to  $A_t^l$ , and  $a_{St}$  is the ratio of the effective number of intermediate goods in  $S$  relative to  $A_t^T$  :

$$a_{Nt} = \left[1 + \frac{A_t^g}{A_t^l} + \frac{A_t^T}{A_t^l} \left(\frac{\psi \xi}{e_t}\right)^{\frac{1}{\theta-1}}\right]; \quad (44)$$

$$a_{St} = \left[\frac{A_t^g}{A_t^T} \left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}} + 1\right]. \quad (45)$$

The market value of companies that currently hold the patent of a local, global and transferred intermediate good are, respectively,

$$v_t = \pi_t - x_t^g + \phi \mathbb{E}_t \left\{ \Lambda_{N,t+1} \left[ \lambda (\Gamma_t^g x_t^g) v_{t+1}^g + (1 - \lambda (\Gamma_t^g x_t^g)) v_{t+1} \right] \right\}, \quad (46)$$

$$v_t^g = \pi_t^g - e_t x_t^T + \quad (47)$$

$$\phi \mathbb{E}_t \left\{ \Lambda_{N,t+1} \left[ \lambda (\Gamma_t^T x_t^T) v_{t+1}^T + (1 - \lambda (\Gamma_t^T x_t^T)) v_{t+1}^g \right] \right\},$$

$$v_t^T = \pi_t^T + \phi E_t \left\{ \Lambda_{N,t+1} v_{t+1}^T \right\}, \quad (48)$$

where the optimal investments in exporting and transferring the production of intermediate goods from  $N$  to  $S$  are given by the optimality conditions

$$1 = \phi \Gamma_t^g \lambda' (\Gamma_t^g x_t^g) \mathbb{E}_t \left\{ \Lambda_{N,t+1} (v_{t+1}^g - v_{t+1}) \right\}, \quad (49)$$

$$e_t = \phi \Gamma_t^T \lambda' (\Gamma_t^T x_t^T) \mathbb{E}_t \left\{ \Lambda_{N,t+1} (v_{t+1}^T - v_{t+1}^g) \right\}. \quad (50)$$

The amount of output devoted to developing new technologies through R&D is determined by the following free entry condition:

$$S_t = \phi \mathbb{E}_t \{ \Lambda_{N,t+1} v_{t+1} (A_{t+1} - \phi A_t) \}. \quad (51)$$

These investments in the development and diffusion of technology allow us to characterize the evolution of technology in both countries.

*Evolution of Technology.*– The evolution of productivity over the medium and long term in  $N$  and  $S$  depends on the dynamics of innovation and international diffusion. New technologies are developed according to the following law of motion:

$$\frac{A_{Nt+1}}{A_{Nt}} = \chi \left( \frac{S_t}{\bar{P}_{Nt}^k K_{Nt}} \right)^\rho + \phi. \quad (52)$$

The optimal diffusion and adoption conditions together with the laws of motion for  $A^g$ , and  $A^T$  yield the following equilibrium dynamics for the stock of global and transferred intermediate goods:

$$\frac{A_{t+1}^g}{A_t^g} = \phi \lambda (\Gamma_t^g x_t^g) \frac{A_t^l}{A_t^g} + \phi (1 - \lambda (\Gamma_t^T x_t^T)); \quad (53)$$

$$\frac{A_{t+1}^T}{A_t^T} = \phi \lambda (\Gamma_t^T x_t^T) \frac{A_t^g}{A_t^T} + \phi. \quad (54)$$

Finally, the definition of  $A_{Nt}$  allows us to determine the stock of local intermediate goods,  $A_t^l$ .

$$A_t^l = A_{Nt} - A_t^g - A_t^T.$$

*Relative Price of Capital.*– The price of new capital is equal to a markup times the marginal cost of production.

$$P_{Nt}^K = \mu^K \theta N_{kNt}^{-(\mu_{kN}-1)} (a_{Nt} A_t^l)^{-(\theta-1)}; \quad (55)$$

$$P_{St}^K = \mu^K \theta \frac{(N_{kSt})^{-(\mu_{kS}-1)}}{\xi} (a_{St} A_t^T)^{-(\theta-1)}. \quad (56)$$

Observe from (55) and (56) that the efficiency gains associated with  $A_{ct}$  and  $N_{ct}^k$  reduce the marginal cost of producing investment. Fluctuations in these variables are responsible for the

evolution in the short, medium and long run of the price of new capital,  $P_{ct}^K$ . However,  $A_{ct}$  and  $N_{ct}^k$  affect  $P_{ct}^K$  at different frequencies.

Because  $A_{ct}$  is a non-stationary state variable, it does not fluctuate in the short term. Increases in  $A_{ct}$  reflect embodied technological change and drive the long-run trend in the relative price of capital. Pro-cyclical investments in the development and diffusion of new intermediate goods lead to pro-cyclical fluctuations in the growth rate of  $A_{ct}$ , generating counter-cyclical movements in  $P_{ct}^K$  over the medium term.  $N_{ct}^k$ , instead, is a stationary jump variable. Therefore, the entry/exit dynamics drive only the short term fluctuations in  $P_{ct}^K$ .

In light of the frequency at which these mechanisms operate, we can decompose  $P_{ct}^K$  into the product of two terms: the medium term wholesale price,  $\bar{P}_{ct}^K$  (defined in 57), that is governed exclusively by technological conditions in the medium term, and a high-frequency component,  $P_{ct}^K/\bar{P}_{ct}^K$ , that is instead governed by cyclical factors:

$$\bar{P}_{ct}^K = (A_{ct})^{-(\theta-1)}. \quad (57)$$

*Balance of Payments.*— The current account balance is equal to the trade balance plus the net income from FDI investments. In equilibrium, a current account deficit needs to be financed by an identical net inflow of capital. Since the only form of capital that flows internationally is foreign direct investment, the financial account balance is equal to the net inflow of FDI:

$$\overbrace{\underbrace{\frac{Q_{Nt}J_{Nt}A_t^T}{\mu_{kNt}a_{Nt}A_t^l} \left(\frac{\psi\xi}{e_t}\right)^{\frac{1}{\theta-1}} + P_t^E E_t^x - \frac{e_t Q_{St}J_{St}A_t^g}{\mu_{kSt}a_{St}A_{St}^T} \left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}}}_{S's \text{ Trade balance}} \underbrace{- \pi_t^T A_t^T}_{S's \text{ Net income}}}_{\text{Current account balance in } S} = - \underbrace{e_t x_t^T A_t^g}_{S's \text{ financial account balance}}. \quad (58)$$

## 4 Model Evaluation

In this section we explore the ability of the model to generate cycles at short and medium term frequencies that resemble those observed in the data in developed and, specially, in developing economies. Given our interest in medium term fluctuations, a period in the model is set to a year. We solve the model by loglinearizing around the deterministic balanced growth path and then employing the Anderson-Moore code, which provides numerical solutions for general first order systems of difference equations. We describe the calibration before turning to some numerical exercises.

## 4.1 Calibration

The calibration we present here is meant as a benchmark. We have found that our results are robust to reasonable variations around this benchmark. To the greatest extent possible, we use the restrictions of balanced growth to pin down parameter values. Otherwise, we look for evidence elsewhere in the literature. There are a total of twenty-six parameters summarized in Table 2. Twelve appear routinely in other studies. Six relate to the process of innovation and R&D and were introduced in Comin and Gertler (2006). Finally, there are six new parameters that relate to trade and the process of international diffusion of intermediate goods and two related to the adjustment costs. We defer the discussion of the calibration of the standard and R&D parameters to the Appendix and focus here on the adjustment costs parameters and those that govern the interactions between  $N$  and  $S$ .

We treat asymmetrically adjustment costs in Mexico and the U.S. based on the ample evidence on the thinner secondary markets for capital goods, more prevalent irreversibilities in plant-level investment, and larger costs of obtaining construction permits and import licenses in Mexico relative to the U.S. (e.g. Gelos and Isgut, 2001, Gwartney et al., 2007, World Bank, and Miller and Holmes, 2009). Comin et al. (2009) estimate  $\xi''_N(1)$  structurally using a similar model with just one country (i.e. the U.S.) and with an endogenous counter-cyclical relative price of capital as our model. They obtain an estimate close to 0 that is not statistically different from 0. Accordingly, we set  $\xi''_N(1)$  to 0.

It is more intricate to calibrate  $\xi''_S(1)$  since, to the best of our knowledge, there are no estimates of investment flow adjustment costs models for developing countries. However, it is possible to use the existing estimates of quadratic adjustment costs for developing countries to obtain a reasonable calibration for  $\xi''_S(1)$ . As discussed above, investment adjustment costs introduce a wedge between the price of installed ( $P_t^I$ ) and uninstalled capital ( $P_t^K$ ). A natural way to calibrate  $\xi''_S(1)$  is to set it to a value that allows our model to match the elasticity of the wedge between  $P_{St}^I$  and  $P_{St}^K$  with respect to investment. One difference between models with quadratic and with investment flow adjustment costs is that in the former the wedge between  $P_{St}^I$  and  $P_{St}^K$  depends only on current investment while in the latter it also depends on future investment (i.e.  $J_{St+1}$ ). Therefore, a natural way to calibrate  $\xi''_S(1)$  is to set it to match the elasticity of the price wedge to a 1% permanent increase in investment.<sup>11</sup> Using the estimates

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<sup>11</sup>In practice, the calibrated value would be the same whether the increment is permanent or only lasts for two periods.

from Iscan (2000), and Warner (1992 and 1994), this exercise yields a value for  $\xi_S''(1)$  of 1.5.

We calibrate the six parameters that govern the interactions between  $N$  and  $S$  by matching information on trade flows, and U.S. FDI in Mexico, the micro evidence on the cost of exporting and the relative productivity of U.S. and Mexico in manufacturing. First, we set  $\xi$  to 2 to match Mexico's relative cost advantage over the U.S. in manufacturing identified by Iyer (2005). We set the inverse of the iceberg transport cost parameter,  $\psi$ , to 0.95,<sup>12</sup> the steady state probability of exporting an intermediate good,  $\lambda^g$ , to 0.0875, and the steady state probability of transferring the production of an intermediate good to  $S$ ,  $\lambda^T$ , to 0.0055. This approximately matches the share of Mexican exports and imports to and from the U.S. in Mexico's GDP (i.e. 18% and 14%, respectively) and the share of intermediate goods produced in the U.S. that are exported to Mexico. Specifically, Bernard, Jensen, Redding and Schott (2007) estimate that approximately 20 percent of U.S. durable manufacturing plants export. However, these plants produce a much larger share of products than non-exporters. As a result, the share of intermediate goods exported should also be significantly larger. We target a value of 33% for the share of intermediate goods produced in the U.S. that are exported. This yields an average diffusion lag to Mexico of 11 years, which seems reasonable given the evidence (e.g. Comin and Hobijn, 2010).

Das, Roberts and Tybout (2007) have estimated that the sunk cost of exporting for Colombian manufacturing plants represents between 20 and 40 percent of their annual revenues from exporting. We set the elasticity of  $\lambda^g$  with respect to investments in exporting,  $\rho_g$ , to 0.85 so that the sunk cost of exporting represents approximately 30 percent of the revenues from exporting. The elasticity of  $\lambda^T$  with respect to FDI expenses,  $\rho_T$ , together with the steady state value of  $\lambda^T$ , determine the share of U.S. FDI in Mexico in steady state. We set  $\rho_T$  to 0.5 so that U.S. FDI in Mexico represents approximately 2% of Mexican GDP.

## 4.2 Impulse response functions

To be clear, the exercises that follow are meant simply as a first pass at exploring whether the mechanisms we emphasize have potential for explaining the data: They are not formal statistical tests. For simplicity, the only two shocks we consider are innovations to the wage

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<sup>12</sup>Interestingly, the value of  $\psi$  required to match the trade flows between the US and Mexico is smaller than the values used in the literature (e.g. 1/1.2 in Corsetti et al., 2008) because of the closeness of Mexico and the US and their lower (nonexistent after 1994) trade barriers.

markup,  $\mu_{ct}^w$ , in  $N$  (U.S.) and in  $S$  (Mexico). Several authors<sup>13</sup> have argued that these shocks may capture important drivers of business cycles. However, we show that the findings are robust to other relevant shocks such as shocks to TFP and to the relative price of capital.

*Response to a U.S. Shock.*— Figure 2 displays the impulse response functions to a U.S. wage markup shock. Solid lines are used for the responses in Mexico while dashed lines represent the responses in the U.S. The response of the U.S. economy to a domestic shock is very similar to the single-country version presented in Comin and Gertler (2006). In particular, a positive wage markup shock contracts domestic labor supply (panel 2) causing a recession (panel 1). In addition to the decline in hours worked, the initial decline in U.S. output is driven by exit in the final goods sector and by a decline in the utilization rate. The response of U.S. output to the shock is more persistent than the shock itself (panel 12) due to the endogenous propagation mechanisms of the model. In particular, the domestic recession reduces the demand for intermediate goods and, hence, the return to R&D investments. This leads to a temporary decline in the rate of development of new technologies but to a permanent effect on the level of new technologies relative to trend. The long run effect of the shock on output is approximately 50% of its initial response.<sup>14</sup>

The U.S. shock has important effects on Mexico’s economy. Upon impact, the decline in Mexico’s output is as large as the decline in U.S. output. Mexico’s recession is driven by two forces: the decline in the demand for Mexican exports to the U.S. (panel 10) and the collapse of Mexico’s investment (panel 4).

Unlike the U.S., the response of Mexico’s output to a U.S. shock is hump-shaped. At the root of this response we find the dynamics of international technology diffusion. In particular, the shock to  $\mu_{Nt}^w$  reduces the return on exporting new intermediate goods and transferring their production to Mexico. As a result, fewer resources are devoted to these investments (panel 7) gradually reducing the stock of intermediate goods in Mexico relative to the steady state (panel 8). Since productivity is determined by the stock of intermediate goods, the slow international diffusion of new technologies also leads to a gradual decline in Mexican productivity which

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<sup>13</sup>E.g. Hall (1997), Gali, Gertler and Lopez-Salido (2002).

<sup>14</sup>In this version of the model, U.S. consumption responds more than U.S. output to a U.S. shock. As shown in Comin and Santacreu (2010), this is a consequence of the simplifying assumption that new technologies diffuse immediately in the U.S. When that is the case, U.S. shocks have large effects on U.S. permanent income leading to large fluctuations in consumption. The introduction of a slow diffusion process as in Comin and Gertler (2006) or Comin and Santacreu (2010) fixes this counter-factual implication. The excess volatility of U.S. consumption does not affect significantly the business cycle dynamics in Mexico.



causes the hump-shaped response of output.<sup>15</sup>

Our model generates large fluctuations in Mexico's productivity. This is at the root of why U.S. shocks have larger effects on Mexico's output than in the U.S. itself. Intuitively, the slow pace of international diffusion of intermediate goods generates a large gap between the stock of technologies available for production in the U.S. and Mexico. As a result, when a shock affects the return to exporting new technologies to Mexico, it induces very wide fluctuations in the flow of new technologies exported to Mexico resulting in wide swings, over the medium term, in the stock of technologies in Mexico. In the U.S., in contrast, there is no such a large stock of technologies waiting to be adopted. Thus, the fluctuations in the stock of technologies and productivity are significantly smaller than in Mexico.

To illustrate further the role of the international diffusion of technologies in Mexico's output dynamics, Figure 3 plots the impulse response function to a shock to  $\mu_{Nt}^w$  after shutting down the extensive margin of trade and FDI channels. When eliminating these linkages between the U.S. and Mexico, the effect of the shock on Mexico's economy is much smaller. Mexico's GDP now declines by about one fifth of the decline in the model with endogenous technology diffusion. Further, the response of Mexico's output diminishes monotonically and it is less persistent than the response of U.S. output.

In contrast, in our model, the response of Mexico's output to a U.S. shock is more persistent than the U.S. response and much more persistent than the shock itself. Thus, endogenous international technology diffusion can provide a microfoundation for the finding of Aguiar and Gopinath (2007) that (in a reduced form specification) the shocks faced by developing countries are more persistent than those faced by developed economies.

The gradual decline in  $A_{St}$  slowly reduces the efficiency of production of new capital leading to a gradual increase in the price of capital (panel 6). The initial response of Mexico's investment to these prospects for the price of capital largely depends on the magnitude of the adjustment costs. Figure 4 reports the impulse response functions to a contractionary  $\mu_{Nt}^w$  shock with no adjustment costs. In the absence of adjustment costs, firms want to time the decline in investment with the peak in the price of new capital. As a result investment does not decline initially but declines sharply later on.

In the presence of adjustment costs, it is very costly to follow this strategy and companies start reducing their investment when the shock hits the economy in anticipation of the future

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<sup>15</sup>In the US the response to the shock is monotonic because of the larger effect of the shock on domestic demand and because technology diffuses faster domestically than internationally.

increase in the price of capital. As a result, a contractionary U.S. shock generates a collapse of Mexico’s investment upon impact (panel 4 of Figure 2) which continues to decline as the price of capital increases and the economy contracts further. As we shall show below, the data supports the model’s prediction of a strong co-movement between U.S. output and Mexico’s investment.

The response of investment to U.S. shocks significantly amplifies the initial response of Mexico’s output to the U.S. shock. (See Figures 2 and 4.) In the absence of adjustment costs, Mexico’s investment does not decline when the shock hits the economy and the only force that drives Mexico’s recession is the decline in demand for Mexican exports to the U.S. Since the share of exports in Mexican GDP is not that large, Mexico’s output declines only by 0.025% in response to a 1% increase in  $\mu_{Nt}^w$ . With adjustment costs, the collapse of investment contributes to Mexico’s recession and output declines by 0.45% in response to the same shock. However, note that in both cases the decline in Mexico’s output eventually exceeds the size of the recession generated in the U.S. Similarly, the hump-shaped response of Mexico’s output is independent of the calibration of the adjustment costs.

*Response to a Mexican Shock*— Figure 5 displays the impulse response functions to a Mexican wage markup shock ( $\mu_{St}^w$ ) in the U.S. (dashed) and in Mexico (solid). There are some striking differences with Figure 2. First, a Mexican shock has virtually no effect in the U.S. This follows from the difference in size between the two economies but also from the fact that technologies flow from the U.S. to Mexico and not otherwise. One consequence of this is that the Mexican shock has a smaller effect than the U.S. shock on the extensive margin of trade and FDI. As a result, the effect of  $\mu_{St}^w$  on Mexico’s GDP is more transitory than the effect of a U.S. shock.

However, the most significant observation from Figure 5 is that Mexican shocks have a larger effect on Mexico’s consumption than on output. This is the result of both the endogenous relative price of capital and the adjustment costs. We explain next the intuition for this result.

By the logic explained above, a contractionary shock leads to a gradual increase in the price of capital. The prospect of a future higher price of capital has two effects. On the one hand, it prevents investment from falling too much initially. (This is also achieved by the adjustment costs. See the contrast with the impulse response to a Mexican shock in the model without adjustment costs in Figure A1.)<sup>16</sup> On the other, it raises current and future interest rates

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<sup>16</sup>Adjustment costs smooth the initial response of Mexico’s investment to the domestic shock. This has two effects. On the one hand, it absorbs resources forcing consumption to decline. On the other, it increases the persistence of the effects of the shocks, amplifying the decline in capital gains from exporting and conducting

despite the lower marginal product of capital due to the recession. Current and future high interest rates induce consumers to save more today, hence reducing their consumption.

Such a significant decline in Mexico’s consumption is feasible for two reasons. First, investment does not fall too much initially. Second, consistent with the data, the trade balance is very counter-cyclical. This, in turn, is a consequence of the persistent response of investment to the shock. Because the response of Mexico’s investment is so persistent, the value of transferring the production of intermediate goods to Mexico,  $v^T$ , declines more than net income from transferred technologies,  $\pi^T$  (panel 9). This leads to a significant decline in FDI inflows into Mexico, a phenomenon that has motivated the “sudden stops” literature (e.g. Calvo, 1998). To reestablish the international equilibrium, the peso depreciates, leading to a trade surplus that absorbs resources and forcing Mexico’s consumption to fall.<sup>17</sup>

Note that one of the key drivers of the high volatility of consumption in Mexico is the counter-cyclicality of the price of capital. As we show below, this prediction is borne by the data. The price of new capital in Mexico is very counter-cyclical at the high frequency with a correlation between HP-filtered output and HP-filtered price of capital of -0.55.<sup>18</sup> Interestingly, the price of new capital is significantly more counter-cyclical in Mexico than in the U.S., where the equivalent correlation is -0.08. This may explain why consumption is as volatile as GDP in Mexico but not in the U.S.

Comparing Figures 2 and 5, it is clear that the high relative volatility of consumption in Mexico is driven by Mexican shocks rather than by U.S. shocks. This is the case because Mexican shocks have a much larger effect on Mexico’s interest rates than U.S. shocks. Intuitively, U.S. shocks trigger a more persistent decline in Mexico’s output than Mexican shocks. As a result, Mexican companies want to cut their investment more drastically in response to them. This leads to a larger initial increase in the price of installed capital ( $P_S^I$ ) which reduces the increase in the slope of  $P_S^I$  due to the gradual increase in the price of new capital ( $P_S^K$ ).<sup>19</sup> Hence the

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FDI to Mexico. As a result, the price of capital in Mexico fluctuates more generating a larger appreciation in Mexico’s price of capital which leads to higher interest rates in response to the shock.

<sup>17</sup>The strong counter-cyclical current account is documented by Neumeyer and Perri (2005) in a sample of developing countries (which includes Mexico).

<sup>18</sup>The counter-cyclicality of the price of new capital in Mexico is robust to other filtering methods. For example, the correlation between the growth rate in the price of capital and HP-filtered output is -0.65. Over the medium term cycle the correlation between Mexico’s price of capital and GDP is -0.71. In the U.S., the correlation between these variables over the medium term is -0.55. For the full post-war period, the correlations in the U.S. are slightly larger (in absolute value): -0.18 for HP-filtered data and -0.66 over the medium term.

<sup>19</sup>As discussed above, a decline in investment leads to an increase in the price of installed capital because the

lower increase in interest rates following a recessionary shock in the U.S. than one in Mexico.

### 4.3 Simulations

We next turn to the quantitative evaluation of the model. To this end, we calibrate the volatility and persistence of wage markups shocks in the U.S. and Mexico and run 1000 simulations over a 17-year long horizon each. Since we intend to evaluate the model's ability to propagate shocks both internationally and over time, we use the same autocorrelation for both U.S. and Mexican shocks and set the cross-country correlation of the shocks to zero. We set the annual autocorrelation of markup shocks to 0.6 to match the persistence of markups in the U.S.<sup>20</sup>

We calibrate the volatility of the shocks by forcing the model to approximately match the high frequency standard deviation of GDP in Mexico and the U.S. This yields a volatility of the wage markup shock of 3.53% in the U.S. and 4.59% in Mexico. This is consistent with the suspicion that developing economies are prone to bigger disturbances than developed countries.

*Volatility.*— Table 1 compares the standard deviations of the high frequency and medium term cycle fluctuations in the data and in the model. Our calibration strategy forces the model to match the volatilities of output in Mexico and the U.S. at the high frequency. In addition, the model also comes very close to matching the volatility of output over the medium term both in Mexico (0.04 vs. 0.037 in the data) and in the U.S. (0.026 vs. 0.015 in the data). Given the low persistence of shocks, matching these moments suggests that the model induces the right amount of propagation of high frequency shocks into the medium term.

The model does a good job in reproducing the volatility observed in the data in variables other than output. It does a remarkable job in matching the volatility of Mexico's consumption both at the high frequency (0.031 vs. 0.031 in the data) and over the medium term cycle (0.044 vs. 0.04 in the data). This is of special interest given the attention that the international macro literature has given to these moments.

The model also generates series for investment, the relative price of capital, bilateral trade flows, the extensive margin of trade and FDI flows that have similar volatilities to those observed

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adjustment costs embedded in (25) imply that lower levels of investment today increase the costs of investment tomorrow.

<sup>20</sup>See Comin and Gertler (2006) for details. Note that, because of the propagation obtained from the endogenous technology mechanisms, this class of models requires a smaller autocorrelation of the shocks to match the persistence in macro variables. In short, they are not affected by the Cogley and Nason (1995) criticism that the Neoclassical growth model does not propagate exogenous disturbances.

in the data both at the high frequency and medium term. For those instances where there are some differences, the empirical volatilities tend to fall within the 95% confidence interval for the standard deviation of the simulated series.<sup>21</sup>

*Co-movement.*— Most international business cycle models have problems reproducing the cross-country co-movement patterns observed in macro variables. First, they lack international propagation mechanisms that induce a strong positive co-movement in output. Second, they tend to generate a stronger cross-country co-movement in consumption than in output, while in the data we observe the opposite (Backus, Kehoe and Kydland, 1992).<sup>22</sup>

Our model fares well in both of these dimensions. Panel A of Table 4 reports the cross country correlations between Mexico and the U.S. for consumption and output, both in the model and in the data. The model generates the strong co-movement between U.S. and Mexico GDPs observed in the data. The average cross-country correlation in our simulations is 0.68 with a confidence interval of (0.3 , 0.89) that contains the correlation observed in the data (0.43). The model also generates a smaller cross-country correlation for consumption than for output, as we observe in the data: The average cross-correlation is 0.055 with a confidence interval that contains the empirical correlation (0.2).<sup>23</sup>

Our model’s ability to match the empirical cross-country co-movement patterns resides in the combination of endogenous diffusion and flow investment adjustment costs. The endogenous international diffusion of technologies generates a strong cross-country co-movement in output and productivity over the medium term. Because of adjustment costs, Mexican firms respond to the future productivity path by adjusting their investment contemporaneously in a pro-cyclical way. This induces the cross-country correlation in output and investment. The large effect that foreign shocks have on domestic investment limits the possibility for a large consumption response, hence inducing a higher cross-country correlation in output than in consumption.

Panel B of Table 4 reports the contemporaneous correlation between the HP-filtered Mexican

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<sup>21</sup>One exception is the growth in the number of intermediate goods exported from the U.S. to Mexico, where our model generates less volatility than we observe in the data counterpart of this variable.

<sup>22</sup>Several authors, including Baxter and Crucini (1995) and Kollmann (1996), have shown that reducing the completeness of international financial markets is not sufficient to match the data along these dimensions. Kehoe and Perri (2002) have made significant progress by introducing enforcement constraints on financial contracts. This mechanism limits the amount of risk sharing, reducing consumption co-movement and increasing the cross-country co-movement in output. However, output still co-moves significantly less than in the data.

<sup>23</sup>The international business cycle literature has also found it difficult to generate positive cross-correlations in investment and employment (Baxter, 1995). As it is clear from Figure 2, our model delivers both.

variables and HP-filtered output in both Mexico and the U.S.<sup>24</sup> Broadly speaking, the model does a very good job in capturing the contemporaneous co-movement patterns within Mexico but also between Mexico and the U.S. The model generates the observed correlation between consumption and output in Mexico (0.61 vs. 0.78 in the data). Note also that, in both model and data, Mexico's consumption is insignificantly correlated with U.S. GDP. This indicates that U.S. shocks do not contribute to the high volatility of Mexico's consumption. This instead is the result of the response of Mexico's consumption to domestic shocks.

A key driver of the volatility of consumption is the dynamics of the price of capital induced by domestic shocks. It is reassuring that the model matches the negative co-movement between Mexico's output and the price of new capital (-0.36 vs. -0.54 in the data). Note also that the model generates an insignificant contemporaneous co-movement between the price of capital in Mexico and U.S. GDP, which is consistent with the evidence (-0.08 in model vs. 0.13 in data). As we show below, this is the case because U.S. shocks drive the price of new capital over the medium term but not so much contemporaneously.

Recall that the strong co-movement between U.S. output and Mexico's investment is the key driver of the large effect that U.S. shocks have on Mexico's GDP. The model also captures the strong co-movement between Mexican investment and output in both the U.S. (0.77 vs. 0.6 in the data) and Mexico (0.69 vs. 0.62 in the data).

Similarly, recall that the medium term productivity dynamics in Mexico result from the cyclical flow of intermediate goods that diffuse to Mexico (i.e. the extensive margin of trade). The model matches quite closely the correlation between our data-counterpart for this variable and output in both the U.S. (0.42 vs. 0.28 in the data) and in Mexico (0.43 vs. 0.42 in the data).

The model also captures broadly the cyclical flow of the bilateral trade flows. In particular, the model generates the strong counter-cyclical flow of Mexico's trade balance. The correlation between Mexico's trade balance and GDP is -0.96 vs. -0.83 in the data. This is the case because, both in the data and in our model, imports from the U.S. co-move more with Mexico's GDP than exports to the U.S. The model also captures the high correlation of bilateral trade flows with U.S. GDP.

A variable where the model underperforms is FDI. Though the model matches cyclical flow of FDI in the data, the correlations with both U.S. and Mexico's GDP are too high. This may reflect the presence of a small but volatile component in actual FDI that does not respond to

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<sup>24</sup>Note that we do not filter the growth rate of intermediate goods since this variable is already trend stationary.

the U.S. or Mexican business cycle.

*Inter-frequency Co-movement.*— One of the motivations for our model was the observation that U.S. high frequency fluctuations lead medium term fluctuations in Mexico. The impulse response functions to U.S. shocks (see Figure 2) show that, qualitatively, the model is able to generate these persistent effects. Table 5 explores the quantitative power of the model to reproduce the inter-frequency co-movement patterns we observe in the data. The first row of Table 5 reports the empirical correlation between lagged HP-filtered U.S. output and the medium term component of Mexico’s output. The second row reports the average of these statistics across 1000 simulations of the model.

The model roughly captures the contemporaneous correlation between high frequency fluctuations in U.S. output and medium term fluctuations in Mexico’s output (0.37 in the model vs. 0.28 in the data). More importantly, the model generates a hump-shaped cross-correlogram between these two variables as we observed in the data. However, in the data the peak correlation occurs after two years (0.53), while in the model it occurs on average after one year (0.42).

A key prediction of our model is that the high frequency response of the extensive margin of trade to U.S. shocks generates counter-cyclical fluctuations in the relative price of capital in Mexico over the medium term. The fourth row in Table 5 presents the average correlation across our 1000 simulations between the medium term component of Mexico’s relative price of capital and HP-filtered U.S. output at various lags. In both actual and simulated data, the contemporaneous correlation is insignificant. The correlation becomes more negative as we lag U.S. GDP in both cases. In the simulated data the peak (in absolute terms) is reached after two years (-0.38), while in the actual data it is reached after three years (-0.5).

Unlike U.S. shocks, Mexican shocks do not have a hump-shaped effect on Mexico’s output over the medium term fluctuations. The correlation between HP-filtered and the medium term component of Mexico’s output is positive and declines monotonically as we lag the series of HP-filtered output.<sup>25</sup> Our model is consistent with this co-movement pattern. (See rows 5 and 6 in Table 5.)

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<sup>25</sup>In the working paper version, we make a similar point by estimating VARs with HP-filtered Mexico’s GDP and the medium term component of several Mexican variables (including GDP).

## 5 Discussion

Next, we explore in more detail the implications of our model and compare it to existing models of trade and international business cycles.

*Other Shocks.*— For concreteness, we have used wage markup shocks as the sole source of fluctuations in our simulations. However, our findings are not driven by the nature of the shocks. To illustrate this, we introduce shocks to TFP and to the price of investment. Figure 6 presents the impulse response functions to a (negative) TFP shock (second row) and a (positive) shock to the price of investment (third row) both in the U.S. To facilitate the comparison, the impulse response function to the U.S. wage markup shock is presented in the first row of the figure.

Qualitatively, the impulse response functions to these shocks are very similar. In all of them there is a large effect upon the impact of the U.S. shock on Mexican output, though the initial response for the two new shocks is smaller in Mexico than in the U.S. All shocks generate a hump-shaped response of Mexico’s output. And in all three cases, the U.S. shock eventually has a larger effect on Mexico than in the U.S. The economics of the response are the same as in the wage markup shock described above. All three shocks trigger a large and persistent slowdown in the flow of new technologies to Mexico and an initial decline in Mexico’s investment larger than the initial decline in consumption. As the productivity of the capital goods sector deteriorates relative to trend, investment declines further generating the hump in the output response.

The response to Mexican shocks is also robust to the nature of the shocks (see Figure 7). For the three Mexican shocks, Mexico’s consumption responds initially more than output and the response of investment is hump-shaped. The similarity of the impulse responses across the three types of shocks suggests that a richer calibration that allowed for a broader set of shocks would capture as well as our simulations the cyclical properties of the Mexican economy and the co-movement patterns with the U.S.

*Sunk vs. Fixed Exporting Costs.*— Much of the theoretical international macro literature that has incorporated the extensive margin of trade has relied on extensions of the Melitz (2003) model. The Melitz model is a two country model with firms of heterogenous productivity and where firms have to incur in some costs to export. Unlike our model, most of the models that have used the Melitz framework to explore business cycle dynamics use fixed cost instead of sunk cost to adjust the range of intermediate goods available for production.

The empirical literature on firm dynamics and exports has found that there are large sunk



costs of exporting new products (e.g. Roberts and Tybout, 1997; Das et al., 2007). However, the use of fixed costs could be defended on the grounds of their tractability if the model with fixed costs has propagation and amplification power similar to that of the model with sunk costs of exporting. To explore whether this is the case, we develop a version of our model where, to export intermediate goods, firms in  $N$  now just need to incur a per period fixed cost. For consistency, we also make the investment in transferring production from  $N$  to  $S$  a fixed cost. Other than these two changes, this version of the model is identical to our original model. This model is basically a variation on the financial autarky model in Ghironi and Melitz (2005) with physical capital and without heterogeneity. We calibrate the fixed costs of exporting and FDI so that in steady state the trade flows are the same as in our original model.

Figure 8 plots the impulse response functions to a U.S. wage markup shock in the model with fixed costs. The differences with our original model are remarkable. In the model with fixed costs of exporting, a contractionary U.S. shock causes a much smaller decline in Mexico's output - only 30% of the decline in U.S. output - than in our model.<sup>26</sup> This is the case because in the model with fixed cost of exporting, the flow of exported and transferred intermediate goods adjusts in response to fluctuations in current profits. In the model with sunk costs, the flow of technologies adjusts in response to fluctuations in the present discounted value of profits. Given the high persistence of profits, the present discounted value of profits fluctuates more and more persistently than current profits. As a result, the range of intermediate goods declines by more over the medium term, generating larger increases in the relative price of capital and larger declines in investment.

The larger drop in U.S. than in Mexico's investment reduces the relative demand for intermediate goods produced in Mexico. To reestablish the international equilibrium, the peso needs to depreciate. The depreciation of the peso, together with Mexico's recession, causes a large drop in FDI and in the number of intermediate goods produced in Mexico. This is precisely the mechanism used in Bergin et al. (2009) to explain the higher volatility of off-shored industries in Mexico than in the U.S. observed in the data.<sup>27</sup>

*Implications for Aggregate Volatility.*— It is clear from Figure 2 that U.S. shocks are a signif-

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<sup>26</sup>This magnitude is consistent with the findings in Ghironi and Melitz (2005).

<sup>27</sup>A different approach to modeling production sharing is followed by Burnstein, Kurz and Tesar (2008). Rather than using variation in the extensive margin, their model assumes a complementarity between domestic and foreign intermediate goods in U.S. production. By changing the importance of the sector where domestic and foreign intermediate goods are complementary, they can generate a significant increase in the correlation between U.S. and Mexican manufacturing output.

icant source of volatility in Mexico's GDP. But what share of Mexican fluctuations is due to U.S. shocks and what share is due to domestic shocks? Similarly, how much do Mexican shocks contribute to the volatility of U.S. GDP?

Table 6 answers these questions by reporting the share of output volatility in each country attributable to each kind of shock. The first two columns focus on the volatility of HP-filtered output while the next two focus on the volatility of output over the medium term cycle. Consistent with Figure 5, Mexican shocks account for a small fraction of U.S. fluctuations (3% at high frequency and 2% over the medium term cycle).

In contrast, U.S. shocks represent a very significant source of Mexican fluctuations. At the high frequency, 64% of Mexico's GDP volatility is driven by U.S. shocks, while over the medium term cycle, U.S. shocks induce 66% of the volatility in Mexico's GDP. This proves the importance of explicitly modelling the U.S. economy to study the business and medium term cycles of the Mexican economy.

## 6 Conclusions

In this paper, we have developed an asymmetric two-country model to study business cycle fluctuations in developing countries. The model introduces two key elements: (i) endogenous and slow diffusion of technologies from the developed to the developing country, and (ii) flow adjustment costs to investment. These mechanisms yield three predictions that we observe in Mexican business cycles.

First, U.S. shocks have a larger effect on Mexico's than on U.S. GDP. Second, the slow diffusion of technologies to Mexico generates a hump-shaped response in Mexican output to U.S. shocks. Third, Mexico's consumption is more volatile than output.

Previous research has already shown that some of these predictions are stylized facts of business fluctuations in developing countries. Thus, our model can be a useful starting point for obtaining a better understanding of business cycle fluctuations in developing countries in general. In doing so, it may be helpful to introduce other relevant linkages not present in our model such as remittances or international capital flows other than FDI.

One of the key contributions of this paper is to extend the business cycle models of endogenous technology (e.g. Comin and Gertler, 2006) to two-country settings. There are several alternative configurations of the two countries that are worth pursuing. One natural variation is to model both countries as advanced economies that develop new technologies through R&D

and adopt each other's technologies. This configuration would naturally capture the interactions between the U.S. and the EU, or the U.S. and Japan. A second variation could be to keep the asymmetry between the developed and developing countries but introduce a low frequency transition by the developing country to its balanced growth path. This configuration would allow to analyze the interdependence between the U.S. and China at the high and medium term frequencies.

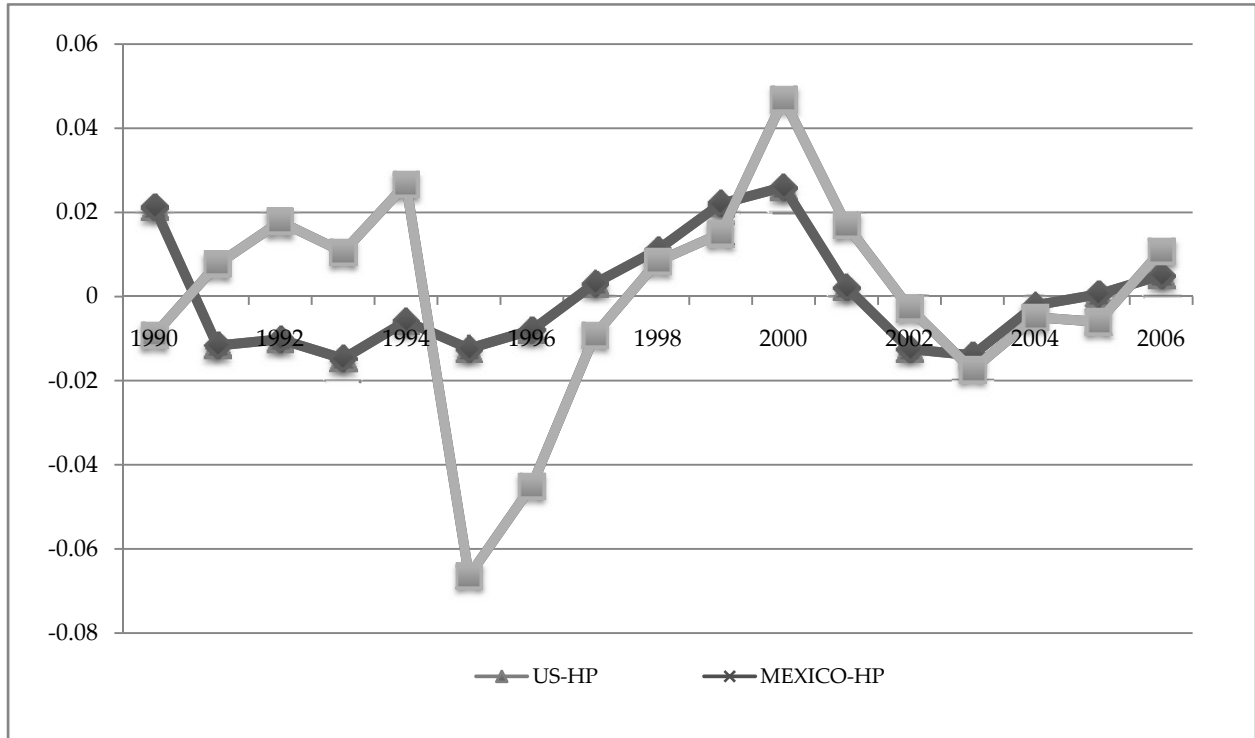
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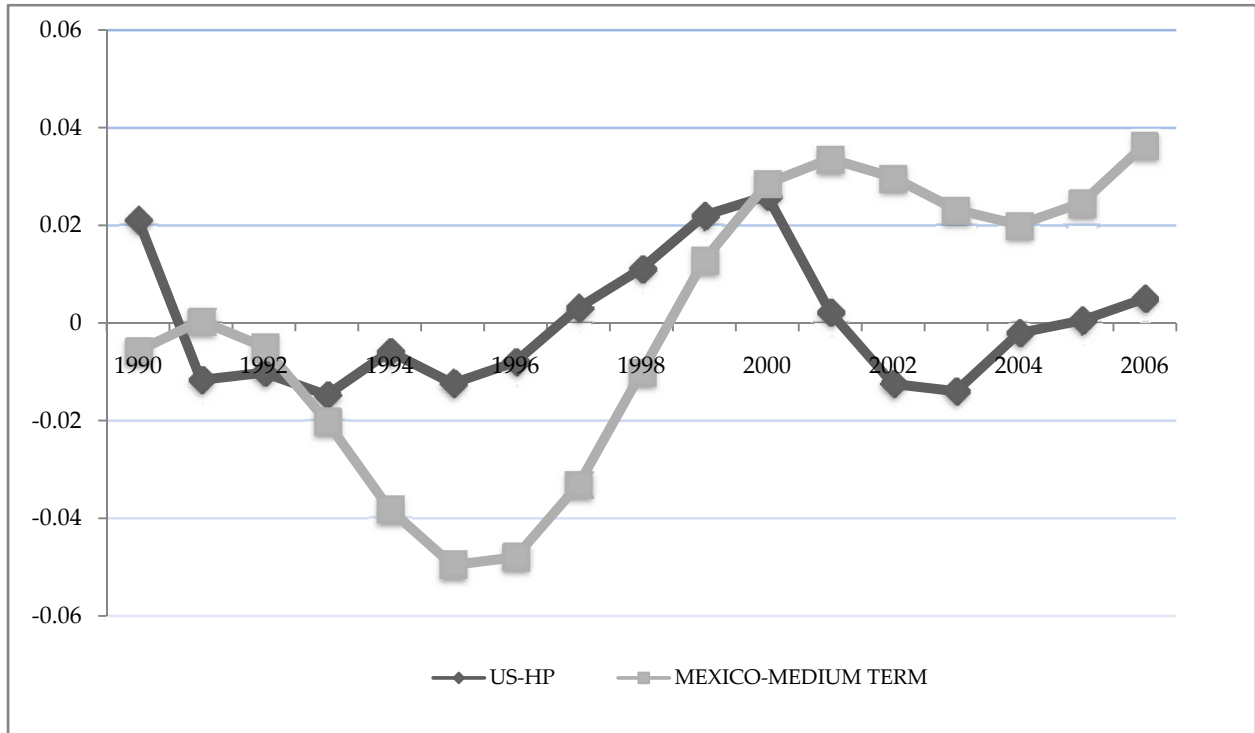
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**Figure 1A: Evolution of HP-filtered GDP per working age person in Mexico and the US**



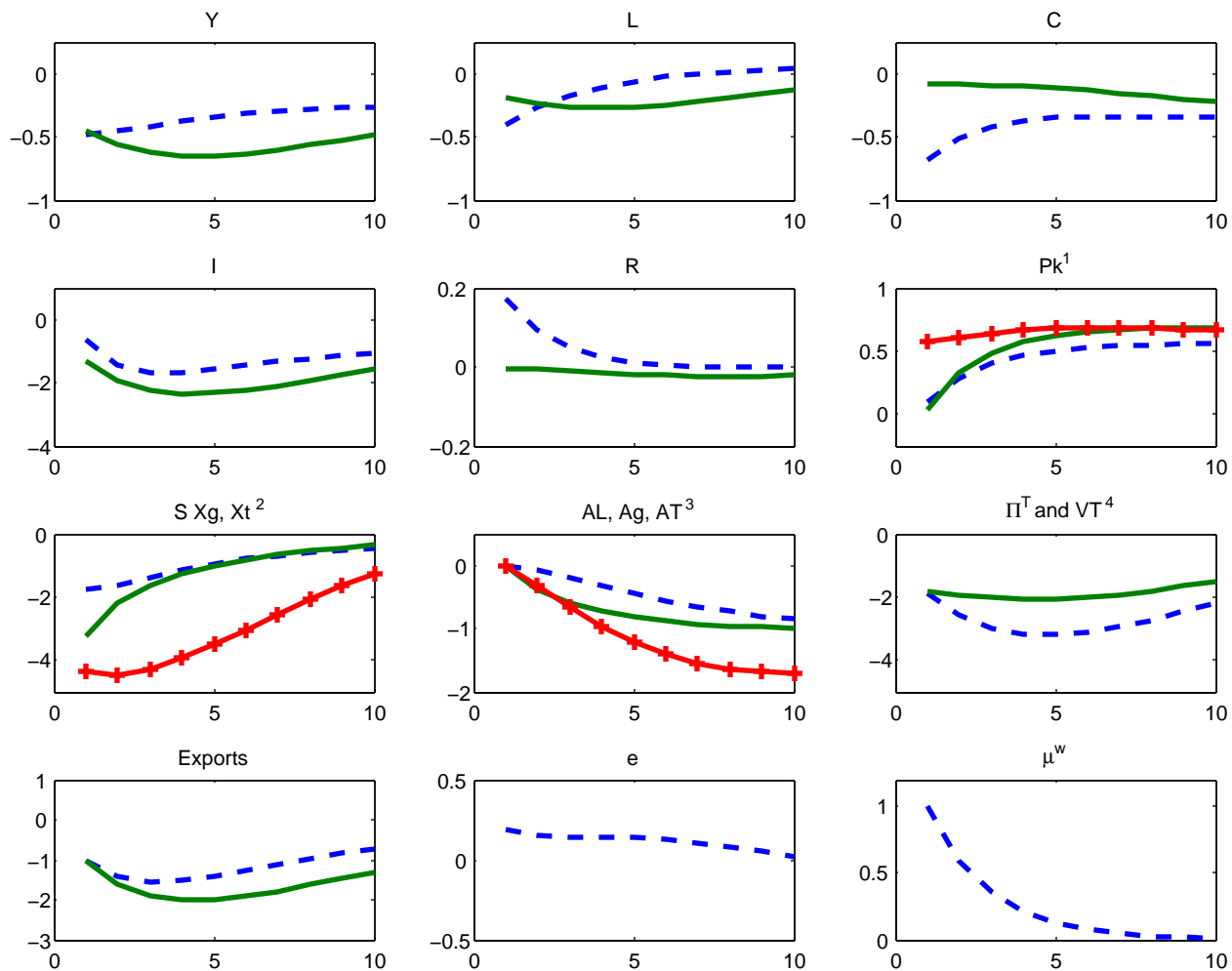
Source: World Development Indicators, Authors' calculations

**Figure 1B: Evolution of GDP per working age person in Mexico and the US filtered at different frequencies**



Source: World Development Indicators, Authors' calculations

Figure 2: Impulse Response Functions for U.S. Wage Markup Shock, Baseline Model (U.S. dash, Mexico, solid)



<sup>1</sup> Price of installed capital in Mexico (+)

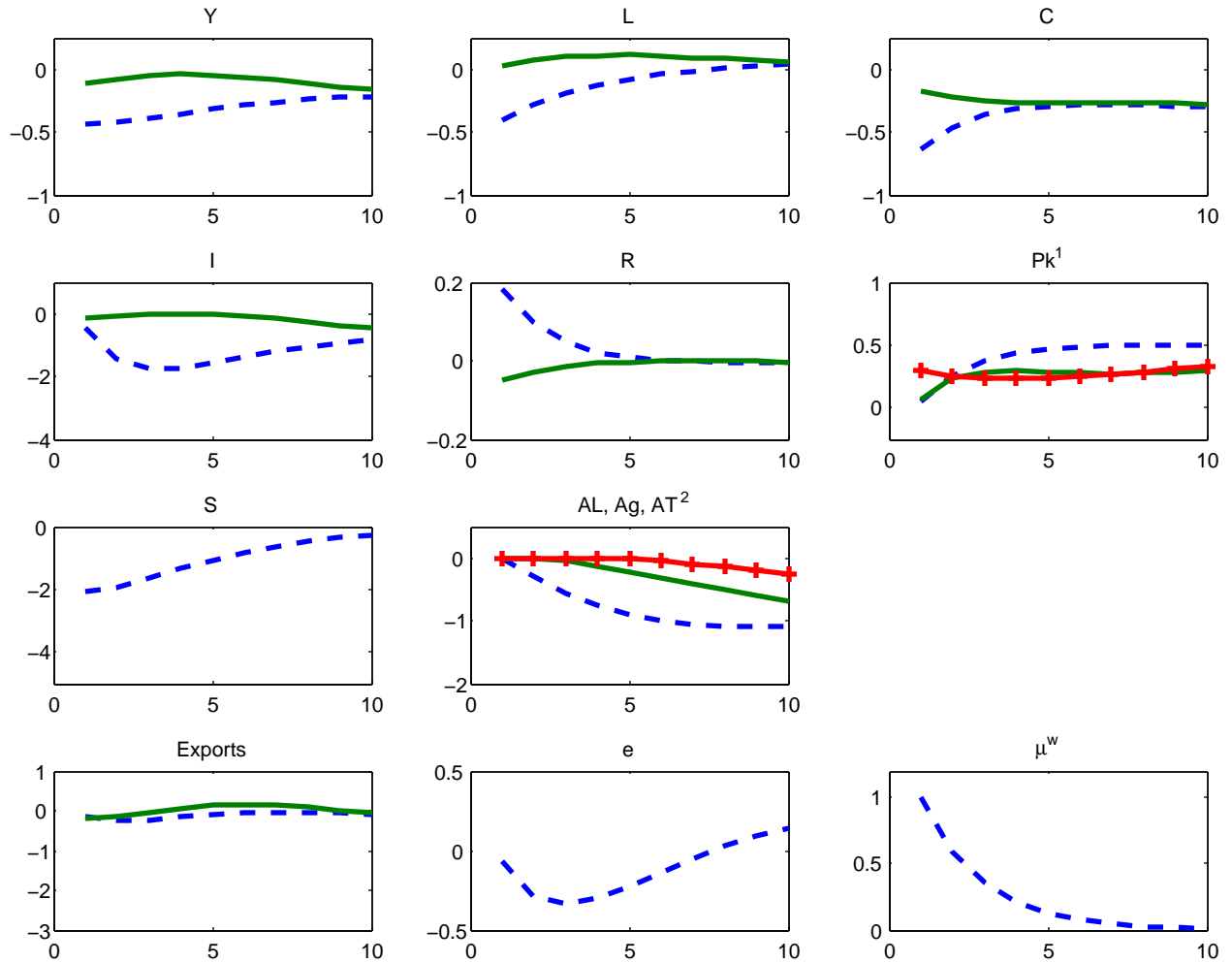
<sup>2</sup> Research and development expenditures (S, --), investments in exporting (Xg, -) and FDI (Xt, --)

<sup>3</sup> Local Intermediate Goods (AL, --), Exported Intermediate Goods (Ag, -) and Transferred Intermediate Goods (AT, --)

<sup>4</sup> Net income from transferred intermediate goods (--), Value of transferred intermediate goods (-)



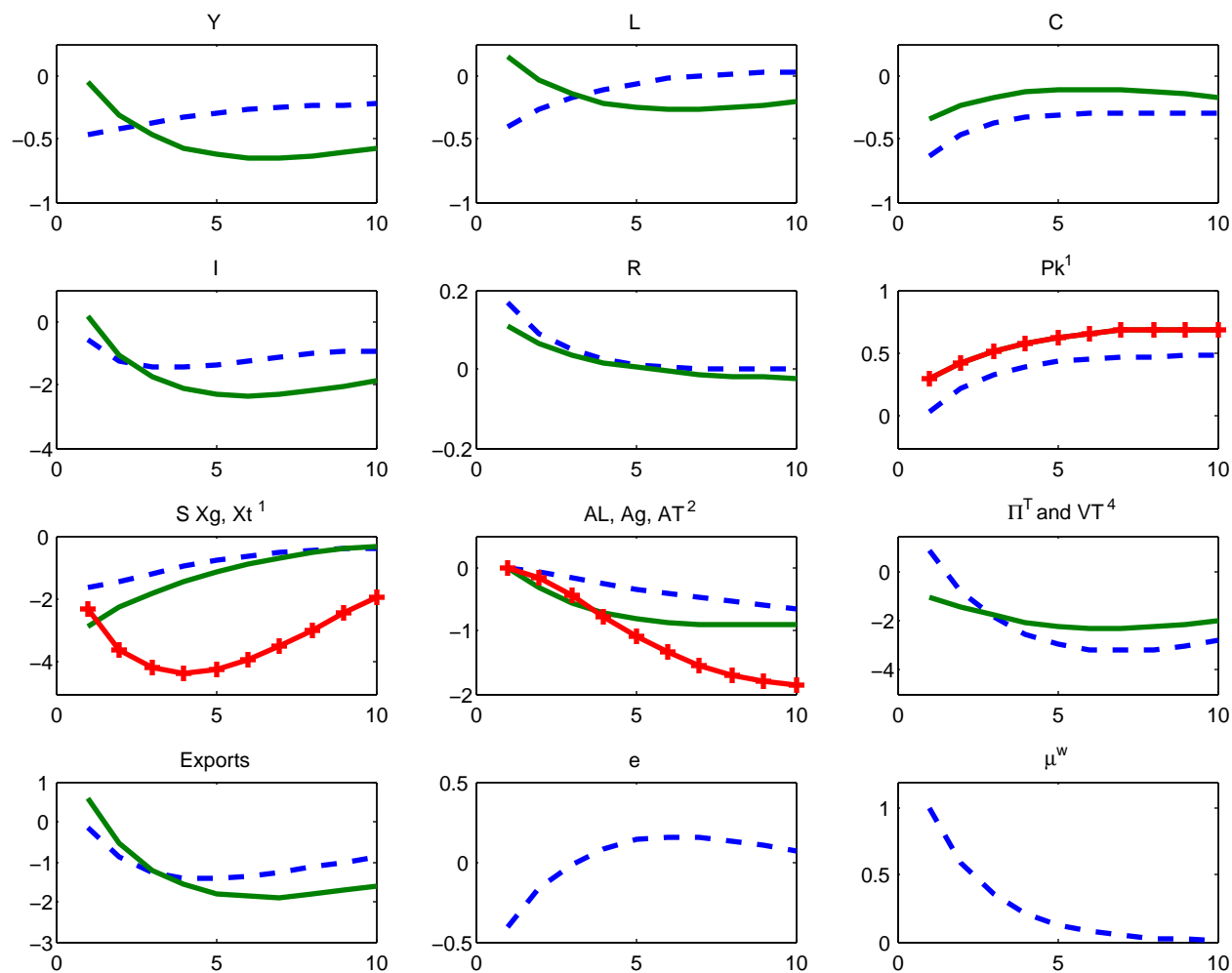
Figure 3: Impulse Response Functions for U.S. Wage Markup Shock, Model Without International Technology Flows (U.S.Dash, Mexico, solid)



<sup>1</sup> Price of installed capital in Mexico (+)

<sup>2</sup> Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transferred Intermediate Goods(AT,-+)

Figure 4: Impulse Response Functions for U.S. Wage Markup Shock, Model Without Adjustment Costs (U.S. Dash, Mexico, solid)



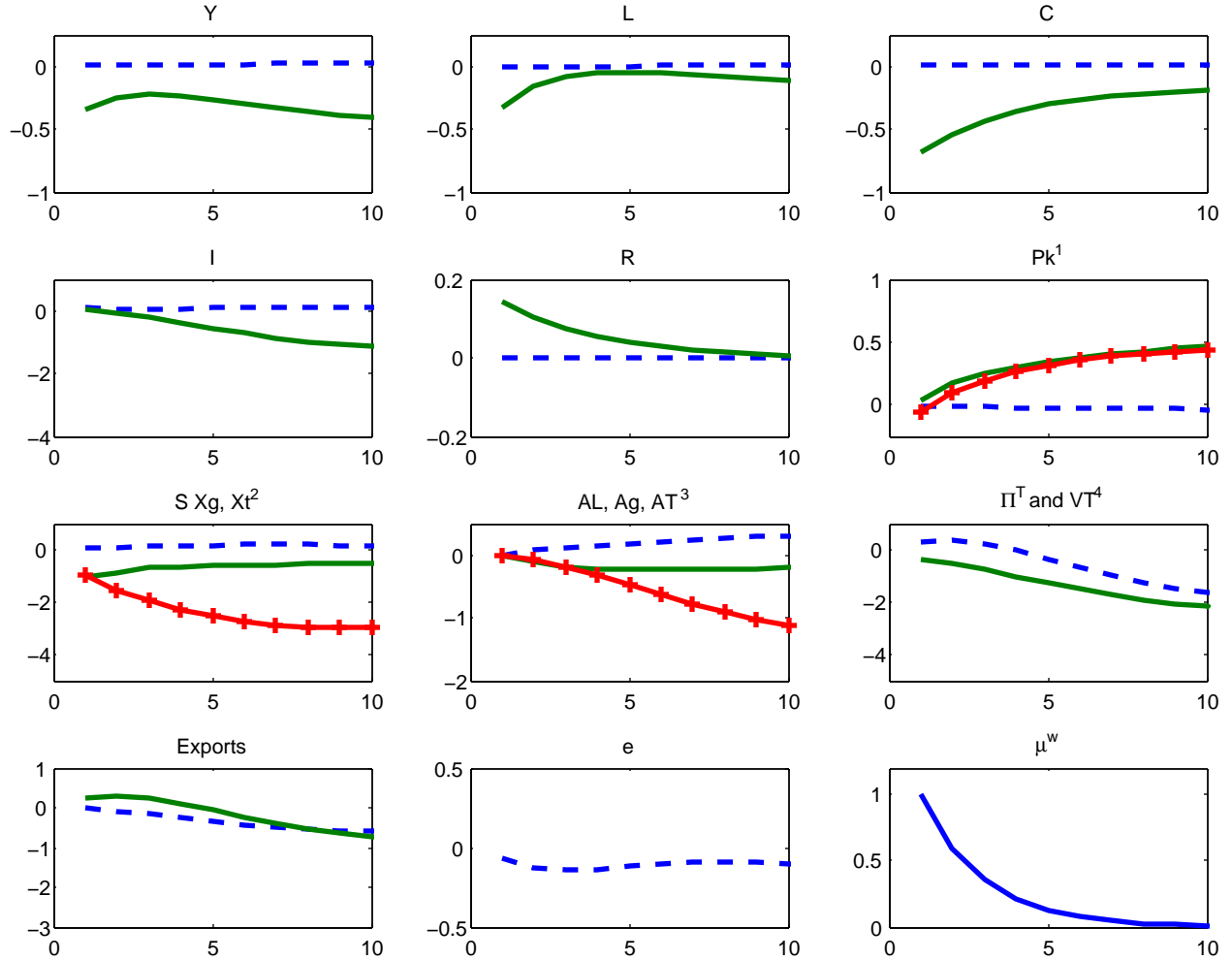
<sup>1</sup> Price of installed capital in Mexico (+)

<sup>2</sup> Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, --)

<sup>3</sup> Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transferred Intermediate Goods(AT,--)

<sup>4</sup> Net income from transferred intermediate goods (--), Value of transferred intermediate goods (-)

Figure 5: Impulse Response Functions for Mexico Wage Markup Shock, Baseline Model (U.S. dash, Mexico, solid)



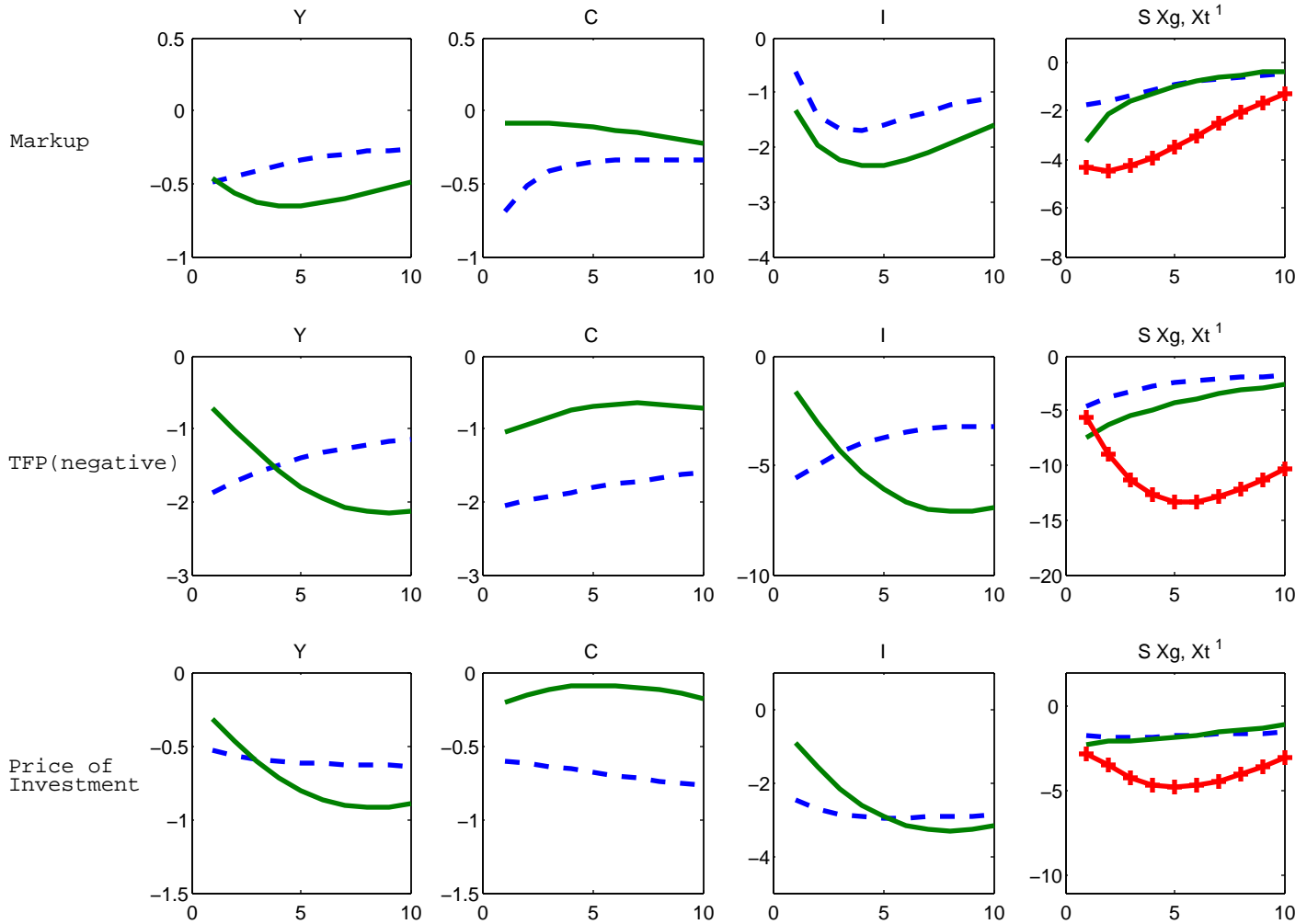
<sup>1</sup> Price of installed capital in Mexico (+)

<sup>2</sup> Research and development expenditures (S, --), investments in exporting (Xg, -) and FDI (Xt, -+)

<sup>3</sup> Local Intermediate Goods (AL, --), Exported Intermediate Goods (Ag, -) and Transferred Intermediate Goods (AT, --+)

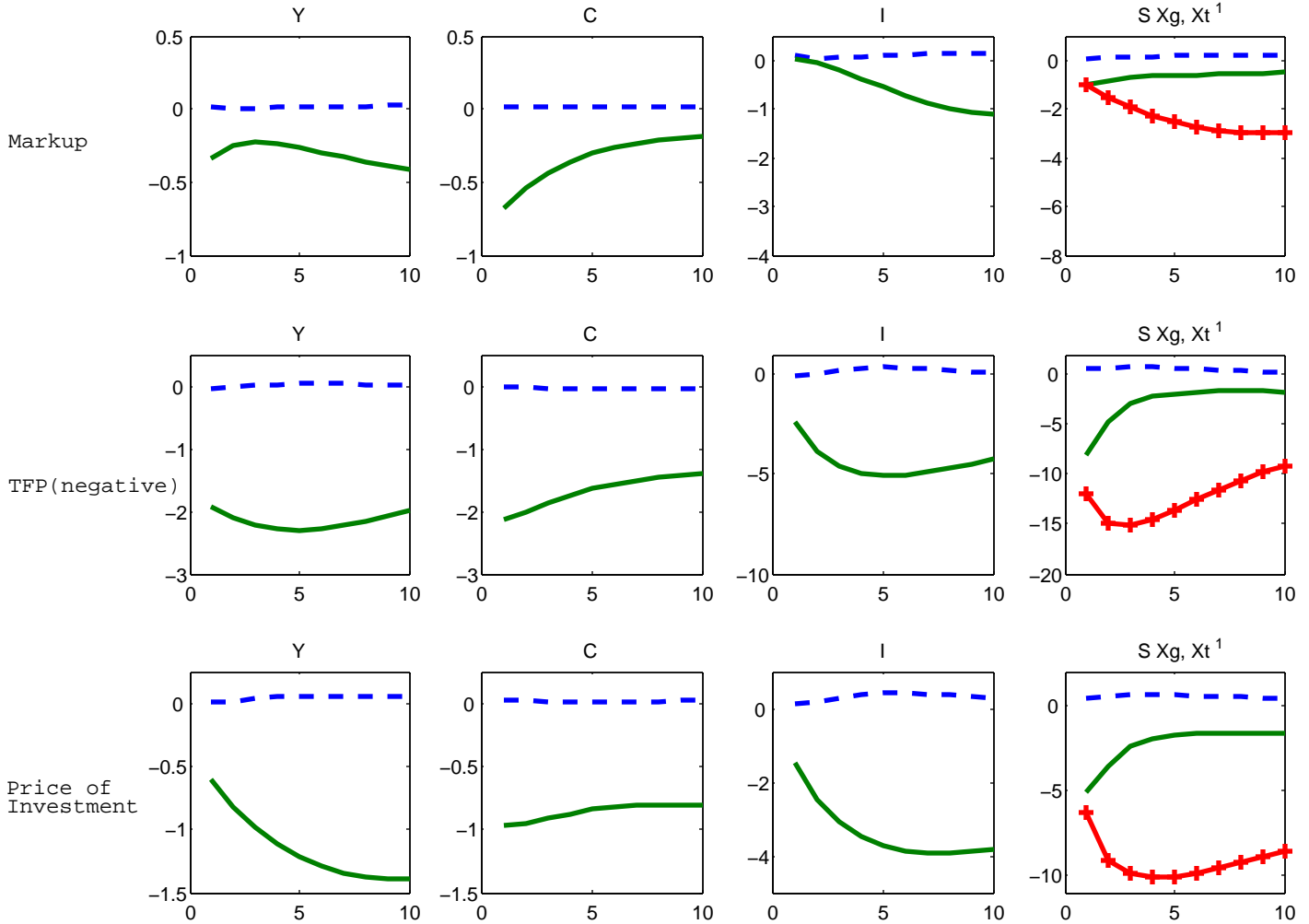
<sup>4</sup> Net income from transferred intermediate goods (Π<sup>T</sup>, --), Value of transferred intermediate goods (VT, -)

Figure 6: Impulse Response Functions for U.S. Wage Markup, TFP and Price of Investment Shocks  
 Baseline Model (U.S. dash, Mexico, solid)



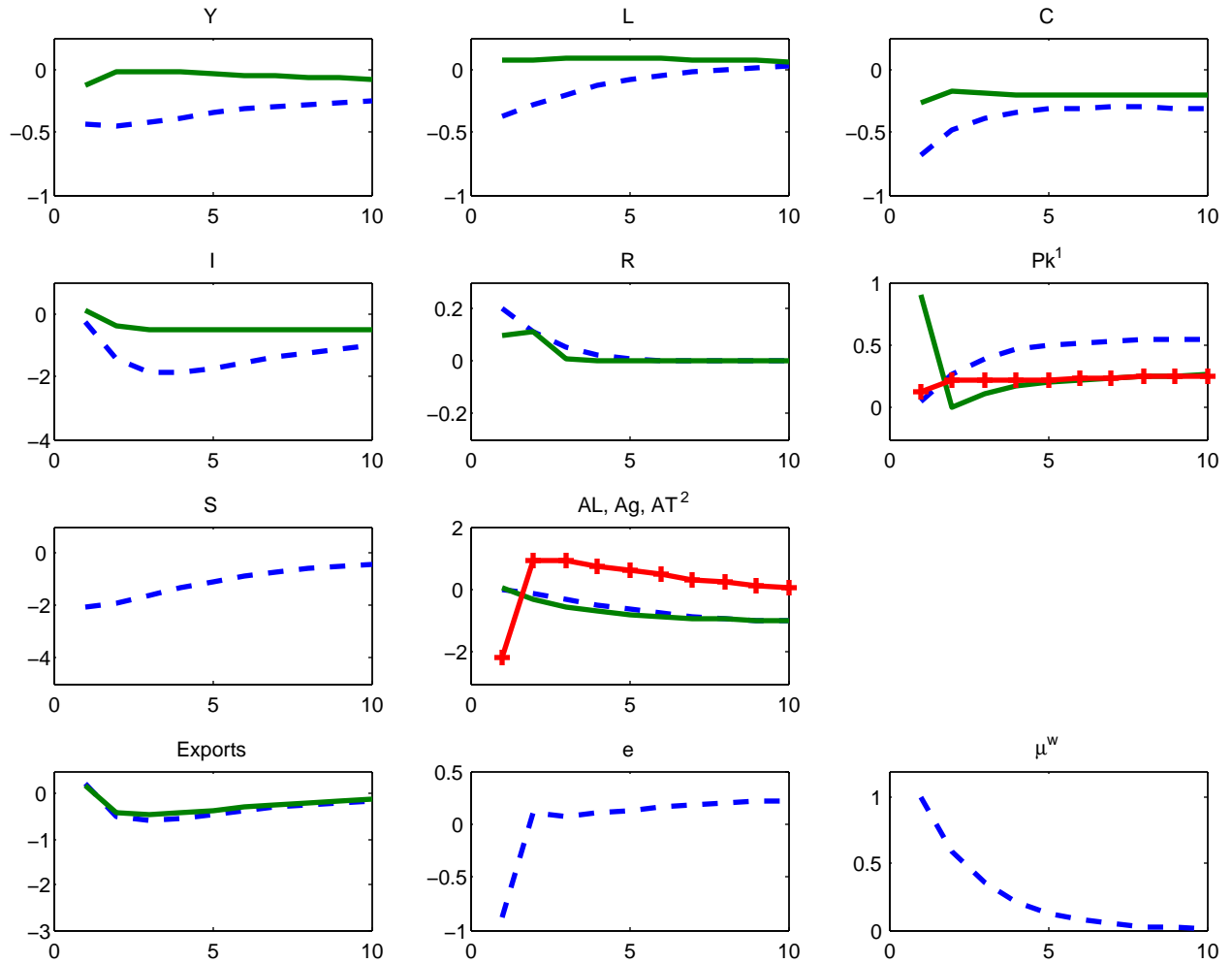
<sup>1</sup> Research and development expenditures (S, --), investments in exporting (Xg, -) and FDI (Xt, --)

Figure 7: Impulse Response Functions for Mexico Wage Markup, TFP and Price of Investment Shocks  
 Baseline Model (U.S. dash, Mexico, solid)



<sup>1</sup> Research and development expenditures (S, --), investments in exporting (Xg, -) and FDI (Xt, -+)

Figure 8: Impulse Response Functions for U.S. Wage Markup Shock in Model with Fixed Costs of International Technology Diffusion. (US dash, Mexico solid)



<sup>1</sup> Price of installed capital in Mexico (+)

<sup>2</sup> Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transferred Intermediate Goods(AT,-+)

Table 1A: Relationship between HP U.S. GDP and medium term component of Mexican GDP and relative price of capital

	Lags	U.S. GDP HP-filtered			
		0	1	2	3
Mexican GDP		0.28	0.49*	0.53**	0.39
Mexican relative price of capital		0.35	0.02	-0.24	-0.5***

Note: Mexican GDP and relative price of capital are filtered with a Band-Pass filter that isolates cycles with periods between 8 and 50 years. Relative price of capital is measured by investment deflator divided by GDP deflator.

Table 1B: Cyclicalities of imported varieties durable manufacturing

	U.S. GDP (HP filtered)	Mexico GDP (HP filtered)
Growth rate varieties imported from U.S.	0.28	0.42
Varieties imported from U.S. (HP-filtered)	0.58***	0.92***
Varieties imported from U.S. (Medium term business cycle)	0.68***	0.86***

Note: Imported varieties are measured as number of 6-digit SIC categories in durable manufacturing with U.S. exports to Mexico with value greater than \$1 Million.

Table 1C: Medium term correlation between varieties imported from U.S. and Mexican relative price of capital and GDP.

	Lags	Durable manufacturing varieties imported from U.S.			
		0	1	2	3
Mexican GDP		0.30	0.44*	0.50**	0.49*
Mexican relative price of capital		0.37	-0.01	-0.38	-0.68***

Note: All series are filtered using a Band-Pass filter that isolates frequencies between 8 and 50 years.

Table 2: Calibration

Parameter	Interpretation	Value
$\beta$	Discount factor	0.95
$\delta$	Depreciation rate	0.1
$G_N/Y_N$	Share of Government Spending	0.2
$G_S/Y_S$	Share of Government Spending	0.1
$U$	Capacity utilization rate in steady state	0.8
$\delta''(U) * U/\delta'(U)$	Elasticity of depreciation w.r.t. $U$	0.15
$\zeta$	Labor supply elasticity	1
$\mu_c$	Markup final goods	1.1
$\mu_k$	Markup capital goods	1.15
$L_N/L_S$	Relative labor supply	3
$Z_{0N}/Z_{0S}$	Exogenous relative TFP $N - S$	3.35
$\phi$	Survival probability	0.9
$b_c$	Operating cost parameter	0.05
$b_c^k$	Operating cost parameter	0.016
$g$	Growth rate of TFP	0.0072
$\chi$	R&D productivity	2.69
$\theta$	Markup intermediate goods	1.5
$\rho$	Elasticity of R&D	0.65
$\xi_N''(1)$	Adjustment costs	1
$\xi_S''(1)$	Adjustment costs	1.5
$\psi$	Iceberg transport costs	0.95
$\lambda^g$	Probability of international diffusion in steady state	0.0875
$\lambda^T$	Probability of production transfer in steady state	0.0055
$\rho^g$	Elasticity of international diffusion	0.8
$\rho^T$	Elasticity of production transfer	0.5



**Table 3 : Volatility Model vs. Data**

MEXICO	High Frequency		Medium term Cycle	
	Data	Model	Data	Model
GDP	0.026	0.024 (0.014 , 0.037)	0.037	0.04 (0.019 , 0.07)
CONSUMPTION	0.031	0.031 (0.019, 0.046)	0.040	0.044 (0.024 , 0.074)
INVESTMENT	0.079	0.068 (0.03 , 0.12)	0.082	0.12 (0.05 , 0.23)
RELATIVE PRICE OF CAPITAL	0.029	0.016 (0.007, 0.028)	0.042	0.035 (0.013 , 0.067)
IMPORTS (FROM US)	0.090	0.050 (0.023 , 0.09)	0.117	0.084 (0.035 , 0.15)
EXPORTS (TO US)	0.090	0.060 (0.027 , 0.11)	0.134	0.105 (0.042 , 0.19)
TRADE SUPLUS/GDP	0.014	0.020 (0.01 2, 0.03)	0.026	0.026 (0.013, 0.046)
GROWTH IN INTERMEDIATE GOODS EXPORTED FROM US TO MEXICO	0.049 (all) 0.047 (dur.)	0.019 (0.01, 0.029)		
FDI/GDP	0.004	0.004 (0.002 , 0.01)	0.005	0.017 (0.006, 0.044)
U.S. GDP	0.013	0.018 (0.01 , 0.027)	0.015	0.026 (0.013 , 0.044)

Note: Period 1990-2006. High frequency corresponds to cycles with periods lower than 8 years and is obtained by filtering simulated data with a Hodrick-Prescott filter. Medium term cycles corresponds to cycles with periods shorter than 50 years and is obtained by filtering simulated data with a Band-Pass filter. The relative price of capital is the investment deflator divided by the GDP deflator. Growth in intermediate goods is not filtered. All stands for all manufacturing sectors while dur stands for durable manufacturing.

**Table 4: Contemporaneous Co-movement patterns**

<b>PANEL A: Cross-country correlations between Mexico and U.S.</b>				
	Data	Model		
<b>GDP</b>	0.43*	0.68 (0.31, 0.89)		
<b>CONSUMPTION</b>	0.2	0.05 (-0.54, 0.059)		
<b>PANEL B: Correlation of Mexican Macro Variables with Mexican and U.S. GDP</b>				
	<b>GDP USA</b>		<b>GDP MEXICO</b>	
	Data	Model	Data	Model
<b>CONSUMPTION</b>	0.02	0.06 (-0.54, 0.61)	0.78***	0.61 (-0.01, 0.91)
<b>INVESTMENT</b>	0.6***	0.77 (0.26, 0.91)	0.62***	0.69 (0.23, 0.93)
<b>RELATIVE PRICE OF CAPITAL</b>	0.13	-0.08 (-0.52, 0.4)	-0.54***	-0.36 (-0.75, 0.13)
<b>IMPORTS (FROM US)</b>	0.61***	0.85 (0.73, 0.93)	0.83***	0.74 (0.32, 0.93)
<b>EXPORTS (TO US)</b>	0.68***	0.70 (0.37, 0.94)	0.08	0.57 (-0.03, 0.9)
<b>MEXICAN TRADE SURPLUS/GDP</b>	0.07	-0.62 (-0.88, -0.17)	-0.83***	-0.96 (-0.99, -0.86)
<b>GROWTH IN INTERMEDIATE GOODS EXPORTED FROM US TO MEXICO</b>	0.2 (all) 0.28 (dur.)	0.42 (-0.12, 0.76)	0.35 (all) 0.42 (dur.)	0.43 (-0.1, 0.78)
<b>FDI/GDP</b>	0.23	0.89 (0.66, 0.98)	0.11	0.73 (0.36, 0.92)

Note: Period 1990-2006. All variables but FDI are scaled by working age population in Mexico. All variables other than growth of intermediate goods have been HP-filtered. The model statistics are the average of the contemporaneous cross-correlations from the Monte Carlo consisting of 1000 17-year long simulations. In parenthesis 95 percent confidence intervals. The relative price of capital is measured by the investment deflator over the GDP deflator. All stands for all manufacturing sectors while dur. stands for durable manufacturing. \* denotes significance at the 10% level, \*\* denotes significance at the 5% level and \*\*\* denotes significance at the 1% level.

**Table 5: Cross-Correlogram Across Frequencies**

		<u>Lags of High Frequency US Output</u>			
		0	1	2	3
<b>MEDIUM TERM COMPONENT MEX GDP</b>					
	Data	0.28	0.49*	0.53**	0.39
	Model	0.37**	0.42**	0.35**	0.18
<b>MEDIUM TERM COMPONENT RELATIVE PRICE OF CAPITAL IN MEX</b>					
	Data	0.35	0.02	-0.24	-0.5**
	Model	-0.14	-0.30*	-0.38*	-0.35
		<u>Lags of High Frequency MEX Output</u>			
		0	1	2	3
<b>MEDIUM TERM COMPONENT MEX GDP</b>					
	Data	0.45**	0.32	0.05	-0.16
	Model	0.52**	0.45**	0.25	-0.01
<b>MEDIUM TERM COMPONENT RELATIVE PRICE OF CAPITAL IN MEX</b>					
	Data	-0.13	-0.32	-0.34	-0.22
	Model	-0.33**	-0.45**	-0.45**	-0.32

Note: Period 1990-2006. High frequency corresponds to cycles with periods lower than 8 years and is obtained by filtering simulated data with a Hodrick-Prescott filter. Medium term cycles corresponds to cycles with periods lower than 50 years and is obtained by filtering simulated data using a Band-Pass filter. The reported measures are the average of the contemporaneous cross correlations from the Monte Carlo consisting of 1000 17-year long simulations. \* denotes significance at the 10% level and \*\* denotes significance at the 5% level.

**Table 6: Decomposition of output volatility**

	<b>High Frequency</b>		<b>Medium Term Cycle</b>	
	<u>US volatility</u>	<u>Mexican volatility</u>	<u>US volatility</u>	<u>Mexican volatility</u>
<b>US Shocks</b>	0.97	0.64	0.98	0.66
<b>Mexico Shocks</b>	0.03	0.36	0.02	0.34

Note: Share of output volatility in the relevant country at the relevant frequency associated to shocks either from the US or Mexico. High frequency fluctuations are isolated using a Hodrick-Prescott filter with filtering parameter 100. Medium term cycle is obtained by using a Band Pass filter that isolates fluctuations associated with cycles of period shorter than 50 years.

## A Calibration

In this appendix we describe the calibration of the twelve standard parameters and the six parameters that relate to the R&D process. We set the discount factor  $\beta$  equal to 0.95, to match the steady state share of non-residential investment to output. Based on steady state evidence we also choose the following numbers: (the capital share)  $\alpha = 0.33$ ; (government consumption to output)  $G_N/Y_N = 0.2$  and  $G_S/Y_S = 0.1$ ; (the depreciation rate)  $\delta = 0.1$ ; and (the steady state utilization rate)  $U = 0.8$ , based on the average capacity utilization level in the postwar period as measured by the Board of Governors. We set the inverse of the Frisch elasticity of labor supply  $\zeta$  at unity, which represents an intermediate value for the range of estimates across the micro and macro literature. Similarly, we set the elasticity of the change in the depreciation rate with respect to the utilization rate,  $(\delta''/\delta')U$ , at 0.15, used, for example, in Jaimovich and Rebelo (2009) and Comin, Gertler and Santacreu (2009). Finally, based on evidence in Basu and Fernald (1997), we fix the steady state gross value added markup in the consumption goods sector,  $\mu^c$ , equal to 1.1 and the corresponding markup for the capital goods sector,  $\mu^k$ , at 1.15.

We set the population of the U.S. relative to Mexico to 3. Similarly, we set the relative productivity levels in final goods production to 3.35 so that U.S. GDP is approximately 12 times Mexico's GDP.

We next turn to the “non-standard” parameters. The estimates for the obsolescence rate have a range from the 4% per year in Caballero and Jaffe (1992) to around 20% in Pakes and Schankerman (1984). Based on this range we consider an obsolescence rate of 10% which implies a value for  $\phi$  of 0.9. The steady state growth rates of GDP and the relative price of capital in the model are functions of the growth rate of new technologies, which in our model are used to produce new capital, and of the exogenous growth rate of disembodied productivity,  $g$ . By using the balanced growth restrictions and matching the average growth rate of non-farm business output per working age person (0.024) and the average growth rate of the Gordon quality adjusted price of capital relative to the BEA price of consumption goods and services (-0.026), we can identify the growth rate of disembodied productivity,  $g$ , and the productivity parameters in the technologies for creating new intermediate goods,  $\chi$ . Accordingly, we set  $g = 0.0072$  and  $\chi = 2.69$ .

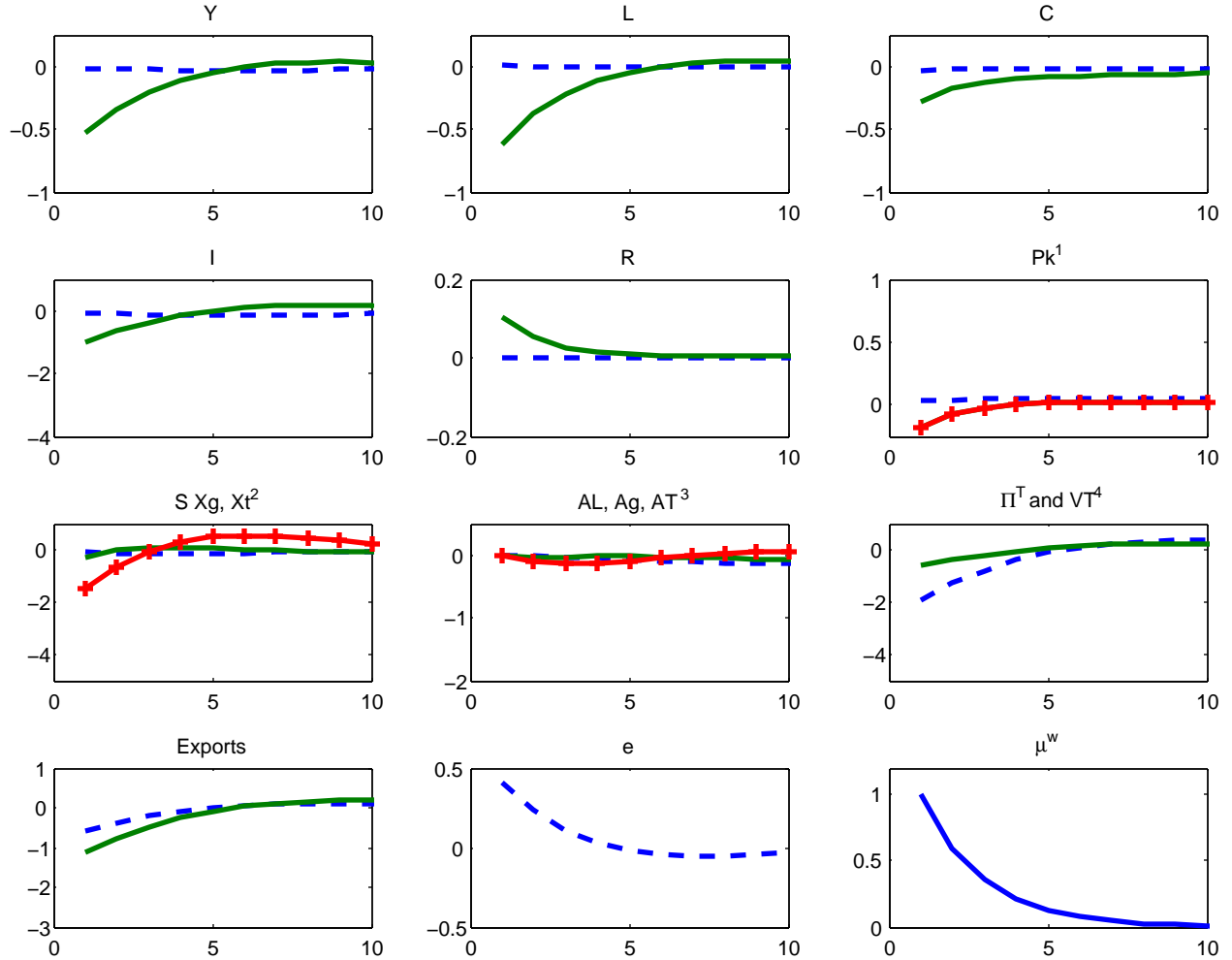
There is no direct evidence on the gross markup  $\vartheta$  for specialized intermediate goods. Given the specialized nature of these products, it seems that an appropriate number would be at the

high range of the estimates of markups in the literature for other types of goods. Accordingly we choose a value of 1.5, but emphasize that our results are robust to reasonable variations around this number.

There is also no simple way to identify the elasticity of new intermediate goods with respect to R&D,  $\rho$ . Griliches (1990) presents some estimates using the number of new patents as a proxy for technological change. The estimates are noisy and range from about 0.6 to 1.0, depending on the use of panel versus cross-sectional data. We opt for a conservative value of 0.65, in the lower range. The calibrations of  $\vartheta$ ,  $\phi$ ,  $\chi$  and  $\rho$  yield an R&D share in U.S. GDP of approximately 1 percent which is in line with the ratio of private R&D expenditures in the investment goods sector to GDP, averaged over the period 1960-2006.

Finally, we fix the autocorrelation of the preference/wage markup shock to 0.6 so that the model generates an autocorrelation that approximately matches that of the total markup as measured by Gali, Gertler and Lopez Salido (2002). We set the autocorrelation of the TFP and price of investment shocks to 0.9.

Figure A1: Impulse Response Functions for Mexico Wage Markup Shock, Model Without Adjustment Costs (U.S. dash, Mexico, solid)



<sup>1</sup> Price of installed capital in Mexico (+)

<sup>2</sup> Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)

<sup>3</sup> Local Intermediate Goods (AL,--), Exported Intermediate Goods (Ag,-) and Transferred Intermediate Goods (AT,-+)

<sup>4</sup> Net income from transferred intermediate goods (Π<sup>T</sup>, --), Value of transferred intermediate goods (VT,-)