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Medium-Term Business Cycles in Developing Countries

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Abstract

Empirical evidence—including the current global crisis—suggests that shocks from advanced countries often have a disproportionate effect on developing economies. Can this account for the fact that aggregate fluctuations are larger and more persistent in the latter than in the former economies? And what are the mechanisms at play? This paper addresses these questions using a model of an industrial and a developing economy trading goods and assets, with (i) a product cycle shaping the range of intermediate goods used to produce new capital in each country, and (ii) investment adjustment costs in the developing economy. Innovation by the advanced economy results in new intermediate goods, at first produced at home, and eventually transferred to the developing economy through direct investment. The pace of innovation and technology transfer is driven by profitability. This process of technology diffusion creates a medium-term connection between both economies, over and above the short-term link through trade. Calibration of the model to match Mexico-United States trade and foreign direct investment flows shows that this mechanism can explain why shocks to the United States economy have a larger effect on Mexico than on the United States itself, and hence why Mexico shows higher volatility than the United States; why business cycles in the United States lead to medium-term fluctuations in Mexico; and why consumption is not less volatile than output in Mexico.

Medium-Term Business Cycles in Developing Countries[1]

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

1   Introduction

At the end of 2007, the US economy entered a recession which, by the first quarter of 2009, had reduced US GDP by 2.2%. The Mexican economy was showing no sign of distress until the US recession began. Despite that, Mexican GDP declined by 7.8% during the same period. This and similar episodes from other developing countries[1] motivate several questions: Why do shocks to developed economies affect developing countries so much? Does the response of developing economies to shocks that originate in their developed neighbors account for the larger volatility of developing economies? More broadly, what ingredients do our models need to incorporate in order to account for the unique features of economic fluctuations in developing economies?

To investigate these questions, we build a two-country asymmetric DSGE model. One of the countries is developed (e.g., the US) while the other is a developing country (e.g., Mexico). The model has two salient features. First, a product cycle structure determines the range of intermediate goods used to produce new capital in each country. Second, we introduce investment flow adjustment costs in the developing economy.

On the product cycle, we follow the approach in Vernon (1966), Wells (1972), and Stokey (1991). New intermediate goods result from R&D expenditures in the US. To increase the range of intermediate goods exported to Mexico (i.e. extensive margin of trade), it is necessary to incur sunk costs. Further investments (i.e. FDI) can facilitate the transfer of the intermediate goods production to Mexico from where they are exported back to the US. On adjustment costs, we adopt the approach in Christiano, Eichenbaum and Evans (2005), where capital accumulation is subject to convex adjustment costs. These costs are incurred when the level of investment changes over time (so that they are zero in the steady state). Moreover, since adjustment costs are at least partially related to the quality of infrastructure and public services, we assume that they are primarily relevant in developing countries.

As in standard trade models, shocks to the US affect the demand for Mexican exports. This generates a positive co-movement between the US and Mexico's outputs in the short term.

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[1]GDP decline over this period in the following sample of countries: Malaysia 7.8%, Philipines 12.1%, Singapore 7.4%, South Korea 3.3%, Taiwan 13.8%, Thailand 7.7%.

But this link is insufficient to generate a larger and more persistent response in Mexico than in the US to a US shock that we see in the data. By making the extensive margin of trade and FDI endogenous, we introduce two mechanisms by which US shocks affect the flow of new technologies to Mexico. In particular, US shocks affect the value of exporting and transferring technologies, inducing pro-cyclical investment in exporting new technologies and FDI flows. Since on average the diffusion of technology takes time, variations in the extensive margin of trade and FDI affect Mexican productivity and output only gradually. This generates a hump-shaped response in these variables in response to a US shock.

Our model generates large fluctuations in Mexican productivity. This is at the root of why US shocks have larger and more persistent effects on Mexican output than in the US 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 US 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 US, in contrast, there is not 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.

Intermediate goods are used to produce new capital and the efficiency of production of new capital is increasing in the number intermediate goods available in the economy. Thus, the reduction in the flow of intermediate goods associated with a US recession generates a gradual increase in the price of Mexican capital. In the presence of adjustment costs, firms respond to the prospect of a higher future price of capital by reducing investment today. This decline in investment is the ultimate driver of the larger initial response of Mexican than US output to a US shock. The decline in the speed of diffusion of intermediate goods to Mexico generates a subsequent decline in Mexican GDP.

Mexican shocks have a very small effect on the US economy. However, they have important effects on Mexican consumption, leading to what might be called excess sensitivity of consumption to output shocks. Even in our context of forward-looking equilibrium, this occurs because of the presence of both adjustment costs to investment and incomplete international credit markets for Mexico. The gradual increase in the price of capital that follows a recessionary shock in Mexico leads to higher real interest rates in Mexico despite the decline in the

marginal product of capital.[2,3] The prospect of higher current and future interest rates induces Mexican consumers to save, depressing consumption. The combination of adjustment costs and prospects of a higher future price of capital reduce the initial decline of investment and generate a counter-cyclical current account. This relaxes the resource constraint enabling a decline in Mexican consumption that is larger than the initial decline in output. As a result, the model is able to generate more volatile consumption than output in developing economies, which is a regularity documented in Aguiar and Gopinath (2007).

Section 4.3 presents evidence on the relevance of the key mechanisms in the model. First, it shows that the flow of new intermediate goods to Mexico – measured by the growth in the number of six-digit manufacturing and durable manufacturing categories with positive US exports to Mexico – co-moves positively with both US and Mexican GDP. Second, the model predicts that this co-movement generates a strong lead of US output over Mexican GDP and over the relative price of capital in Mexico. We indeed find that these predictions are borne by the data. Third, the model also predicts that one key aspect of the large effect that US shocks have on Mexican GDP is the effect that they have on Mexican investment. Consistent with this, we find a strong positive co-movement between US GDP and Mexican investment in the data. Finally, a key driver of the high volatility of consumption in Mexico is the counter-cyclicality of the price of capital in Mexico which generates a similar cyclical pattern in interest rates. The data also support this mechanism since we find that the relative price of capital is strongly counter-cyclical in Mexico and more so than in the US. It is important to remark that, in addition to matching these qualitative features of the data, our model provides a quantitatively accurate account of their strength.

Our model is related to several literatures. First, the empirical literature on synchronization of business cycle fluctuations across countries (e.g. Frankel and Rose 1997 and 1998) has shown that countries that trade more tend to have more synchronized business cycles.[4] Second, the literature on medium-term business cycles (Comin and Gertler, 2006, and Comin, Gertler and Santacreu, 2009) has shown that endogenous R&D and technology adoption mechanisms introduce significant endogenous propagation and amplification. This literature, however, has considered single-country models of developed economies and therefore is not suited to study

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[2]In section 4 we provide evidence on the strong counter-cyclicality of the price of capital in Mexico.

[3]The counter-cyclicality of real interest rates in developing countries is emphasized by Neumeyer and Perri (2005).

[4]More recently, Sosa (2008) has investigated the co-movement patterns of US and Mexico using VARs .

the co-movement between developed and developing countries.

Third, our model is related to Aguiar and Gopinath (2007), who argue that, in a reduced form sense, shocks to developing countries are more persistent than shocks to developed economies and use this to explain the higher volatility of consumption relative to output observed in developing countries. Our model provides a microfoundation for their assumption based on the slow diffusion of technologies.

A fourth related literature uses small open economy macro models to explore business cycles in developing countries (e.g. Neumayer and Perri, 2005, Mendoza, 2008, and Tsyrennikov, 2007). This approach does not explicitly model the link between developed and developing economies. It instead assumes that domestic interest rates are linked to the world interest rates which are exogenous. As a result, they are not well suited to explain the observed lead-lag relationship between Mexico and the US. Some of these models have been successful in generating a higher volatility in consumption than output with the introduction of frictions in capital markets. However, the type of capital flows they rely on (international borrowing and lending) has become a small fraction of international capital flows to developing countries. As shown by Loayza and Serven (2006), approximately 70% of the capital flows to developing countries since 1990 have been FDI.[5] Our model takes the opposite approach of assuming that FDI is the only international capital flow. In this sense, it is complementary to the SOE models.

Finally, our model is related to the new trade literature that has emphasized the relevance of the extensive margin of trade (i.e. how many intermediate goods are traded) to explain trade volumes (Melitz, 2003, Kehoe and Ruhl, 2002, and Bernard et al., 2007) and international co-movement (Melitz and Ghironi, 2005, and Bergin, Feenstra, and Hanson, 2009).[6] The elegance and tractability of these models follows, in part, because the number of intermediate goods exported is not a state variable. This feature, however, makes difficult for these models to generate the observed hump-shaped effect of US shocks on Mexican output. The static nature of the extensive margin decision implies that it is basically driven by fluctuations in relative

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[5] The FDI share is even larger when restricting attention to private capital flows and when focusing in Latin America and Asia.

[6] This latter paper is the most complementary to ours. It develops an elegant model of outsourcing to explain the co-movement between the manufacturing sectors in the US and Mexico as well as the higher volatility in the Mexican manufacturing sectors than in the US. Co-movement follows from perfect international insurance of consumption and from the possibility of outsourcing production. The higher volatility follows from the smaller size of the outsourced sector in Mexico and because the cyclicality of US wages dampens the effects of US demand shocks on domestic demand triggering outsourcing to Mexico.

wages. However, in the data, US wages have been almost acyclical over the last 20 years.[7] Hence, they are surely not the main source of co-movement between Mexico and the US. A final difference between our model and those of the new trade literature is that, since we have investment in physical capital, output and consumption in our model are quite different objects and we can attempt to understand why consumption is more volatile than output in developing countries.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 discusses the symmetric equilibrium and provides some intuition about the key mechanisms. Section 4 evaluates the model. Section 5 concludes.

2　Model

Before presenting the model, we briefly describe its main features. Ours is a two-country model with trade in intermediate goods. The number of intermediate goods available for production determines the technology to produce new capital. Three margins determine the number of intermediate goods available for production in each country: (i) R&D investments create new intermediate goods in the North (N); (ii) investments in exporting intermediate goods enlarge the set of intermediate goods exported to the South (S); (iii) FDI transfers the production of the intermediate good to S. Capital markets are assumed to be perfect within countries but international capital flows other than FDI are ruled out.

2.1　Resource constraints

Let Y_{ct} be gross final output. In each country, final output may be used for consumption, C_{ct}, investment, I_{ct}, paying overhead costs, O_{ct}, and government spending, G_{ct}. In addition, $N's$ output can be used to conduct research and development, S_t, that leads to new intermediate goods and to make intermediate goods suitable for export to S, X_t^g. $N's$ firms can also conduct foreign direct investment by using $S's$ final output to transfer the production of the intermediate goods to S, X_t^T. The aggregate resource constraints can then be written as follows:

$$Y_{Nt} = C_{Nt} + I_{Nt} + O_{Nt} + G_{Nt} + S_t + X_t^g \tag{1}$$

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[7]The correlation between HP-filtered output and real wages since 1990 in the US is 0.2.

$$Y_{St} = C_{St} + I_{St} + O_{St} + G_{St} + X_t^T \tag{2}$$

In turn, let J_{ct} be newly produced capital and $\delta(.)$ be the depreciation rate of capital. Then capital evolve as follows:

$$K_{ct+1} = (1 \square \delta(U_{ct}))K_{ct} + J_{ct}(1 \square \xi_c \left(\frac{J_{ct}}{J_{ct-1}(1 + g_K)} \right)) \tag{3}$$

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 $\xi_c(.)$ 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.[8] Note also that the function $\xi_c(.)$ is indexed by c reflecting international asymmetries in the magnitude of adjustment costs.

Next, let P_{ct}^k be the price of this capital in units of domestic final output. Given competitive production of final capital goods,

$$J_{ct} = (P_{ct}^K)^{-1} I_{ct} \tag{4}$$

A distinguishing feature of our framework is that P_{ct}^k evolves endogenously in each country. One of the key sources of variation in P_{ct}^k is the pace at which new technologies embodied in new intermediate goods arrive in the economy which depends on the agents response to overall macroeconomic conditions, as we describe below.

2.2   Capital

Physical capital is immobile across countries. It is produced in two stages. First, a continuum of N_{ct}^K differentiated firms construct new capital. Each uses as input the continuum A_{ct} of the differentiated intermediate capital goods available for production in the economy. Let $J_{ct}(r)$ be new capital produced by firm r and $I_{ct}^r(s)$ the amount of intermediate capital the firm employs from supplier s. Then

$$I_{ct}(r) = \left(\int_0^{A_{ct}} I_{ct}^r(s)^{\frac{1}{\theta}} ds \right)^{\theta} \tag{5}$$

with $\theta > 1$. Note that each supplier s of intermediate capital goods has a bit of market power. Profit maximization implies that the supplier sets the price of the s intermediate capital good

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[8]This formulation is now standard in macro models (Christiano, Eichembaum and Evans (2005), Jaimovich and Rebelo (2008), and Comin, Gertler and Santacreu (2009)).

as a fixed markup θ times the marginal cost of production. In N, it takes one unit of final output to produce one unit of intermediate. So, the marginal cost is unity. To capture the comparative advantage of the South in assembling manufacturing goods (e.g. Iyer, 2005), we assume that it takes $1/\xi (< 1)$ units of country S output to produce a unit of a intermediate good in S.

In addition, there is an iceberg transport cost of shipping the good internationally. In particular, $1/\psi$ (where $\psi < 1$) units of the good need to be shipped so that one unit arrives.

Observe that there are efficiency gains in producing new capital from increasing the number of intermediate inputs, A_{ct}. These efficiency gains reflect embodied technological change and are the main source of variation in the relative price of capital, P_{ct}^k, over the long and medium term.

New capital, J_{ct}, is a CES composite of the output of the N_{ct}^K capital producers, as follows:

$$J_{ct} = \left(\int_0^{N_{ct}^K} I_{ct}\left(r\right)^{\frac{1}{\mu^K}} dr \right)^{\mu^K} \tag{6}$$

with $\mu^K > 1$.

We allow the number of capital producers N_{ct}^K to be endogenously determined by a free entry condition in order to generate high frequency variation in the real price of capital that is consistent with the evidence (e.g. Comin and Gertler, 2006 and section 4.2 in this paper).[9] We can decompose P_{ct}^K into the product of two terms: the medium term wholesale price, $\overline{P}_{ct}^K$, 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.[10]

We assume that the per period operating cost of a final capital good producer, o_{ct}^k, grows with the medium term replacement value of the capital stock. Formally,

$$o_{ct}^k = b_c^k \overline{P}_{ct}^K K_{ct} \tag{8}$$

where b_c^k is a constant. As in Comin and Gertler (2006), this captures the notion that the operating costs are increasing in the sophistication of the economy, as measured by $\overline{P}_{ct}^k K_{ct}$, and

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[9] 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.

[10] In particular,

$$\bar{P}_{ct}^K = (A_{ct})^{-(\theta-1)} \tag{7}$$

guarantees balanced growth. At the margin, the profits of capital producers must cover this operating cost. This arbitrage condition pins down N_{ct}^k :

$$\frac{\mu^K \square 1}{\mu^K} \frac{P_{ct}^K J_{ct}}{N_t^K} = b_c^k \overline{P}_{ct}^K K_{ct} \tag{9}$$

Optimal investment

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. As a result, firms will tend to smooth out investment flows. Formally, the wedge is given by the following condition

$$
\begin{aligned}
P_{ct}^K &= P_{ct}^I \left[1 \square \xi_c \left(\frac{J_{ct}}{J_{ct-1}\left(1+g_K\right)} \right) \square \xi_c' \left(\frac{J_{ct}}{J_{ct-1}\left(1+g_K\right)} \right) \frac{J_{ct}}{J_{ct-1}\left(1+g_K\right)} \right] \\
&\quad + E_t \left[P_{ct+1}^I \beta \Lambda_{c,t+1} \xi' \left(\frac{J_{ct+1}}{J_{ct}\left(1+g_K\right)} \right) \left(\frac{J_{ct+1}}{J_{ct}\left(1+g_K\right)} \right)^2 \right]
\end{aligned} \tag{10}
$$

where

$$\Lambda_{c,t+1} = C_{ct}/C_{ct+1}.$$

2.3   Technology

The efficiency of the production of new capital goods depends on the number of intermediate goods available for production A_{ct}. Next, we describe the processes of invention, international diffusion and transfer of production which is inspired by the product lifecycle literature (Vernon, 1966). Intermediate goods are invented in country N and at this first stage they are local (i.e. can only be used in N). After successfully undertaking a stochastic investment, the good becomes global (i.e. can be exported to S). At a final stage, the production of intermediate goods can be transferred to S in order to benefit from the comparative advantage of S at producing intermediate goods. This entails another stochastic investment though this time it is in terms of country S output. These investments constitute the flow of FDI from N to S. We denote by A^l, A^g and A^T the stock of local, global and transferred intermediate goods. The total number of intermediate goods available in each country is therefore given by

$$
\begin{aligned}
A_{Nt} &= A_t^l + A_t^g + A_t^T \tag{11} \\
A_{St} &= A_t^g + A_t^T. \tag{12}
\end{aligned}
$$

8

Technology flows determine trade flows. Country N exports to S the A^g intermediate goods which have become exportable while S exports to N the A^T intermediate goods whose production has been transferred to S. The only other good that is traded in this economy is energy as we discuss below. Next we present the conditions that characterize the technology dynamics in each economy.

Creation of new intermediate goods

Innovators in N create new intermediate goods by investing final output into R&D activities. In exchange they are granted a patent which ensures the monopolistic rents from being the sole producer of the intermediate good. R&D is financed with loans from the households. Let $S_t(p)$ be the total amount of R&D by innovator p. Let φ_t be a productivity parameter that the innovator takes as given and let $1 - \phi$ the probability that any existing intermediate good becomes obsolete in the subsequent period. Then, the law of motion for the stock of technologies developed by innovator p is:

$$A_{Nt+1}(p) - A_{Nt}(p) = \varphi_t S_t(p) - (1 - \phi) A_{Nt}(p) \tag{13}$$

We assume that φ_t depends on the aggregate stock of innovations in N, A_{Nt}, the medium term wholesale value of the capital stock $\overline{P}_{Nt}^k K_{Nt}$, and aggregate research and development expenses S_t as follows:

$$\varphi_t = \chi A_{Nt} \left(\frac{S_t}{\overline{P}_{Nt}^k K_{Nt}} \right)^{\rho-1} (\overline{P}_{Nt}^k K_{Nt})^{-1} \tag{14}$$

with $0 < \rho \leq 1$ and where χ is a scale parameter. This formulation is borrowed from Comin and Gertler (2006) and permits us flexibility in calibrating the impact of R&D while ensuring the existence of a balanced growth path without scale effects.

In equilibrium, agents engage in R&D activities until the cost of developing a new intermediate good (LHS) equalizes its expected market value (RHS).

$$1/\varphi_t = \phi R_{Nt}^{-1} \mathbb{E}_t v_{t+1}, \tag{15}$$

where v_t is the market value of the patent to produce a local intermediate good. v_t can be defined by the following Bellman equation

$$v_t = \max_{x_t^g} \pi_t - x_t^g + R_{Nt}^{-1} \phi \mathbb{E}_t \left[\lambda \left(\Gamma_t^g x_t^g \right) v_{t+1}^g + \left(1 - \lambda \left(\Gamma_t^g x_t^g \right) \right) v_{t+1} \right], \tag{16}$$

where π_t denotes the per period profits of a local intermediate goods producer, x_t^g is the number of units of final output spent in adapting the intermediate good for use in country S, $\lambda(\Gamma_t^g x_t^g)$

is the associated probability of a successful adaptation where $\lambda(.)$ satisfies $\lambda' > 0$, $\lambda'' < 0$, v^g is the market value of a global intermediate good, and Γ_t^g is a scaling factor, taken as exogenous by the innovator, which adjusts slowly over time, and ensures balanced growth, and is equal to

$$\Gamma_t^g = \frac{b^g}{(\overline{P}_{Nt}^k K_{Nt}/A_t^l)} \tag{17}$$

where b^g is a positive constant.

Investment in exporting

Intermediate goods producers in N can expand the market for their products by exporting them to S. Prior to this, however, the producer must successfully market the intermediate good in S and adapt it to be suitable for production in S. The optimal intensity of this investment 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:

$$1 = \overbrace{R_{Rt+1}^{-1}\phi}^{\text{discounting}} \overbrace{\Gamma_t^g \lambda' \left(\Gamma_t^g x_t^g\right)}^{\text{Mg. } \triangle \text{ in } \lambda^g} \overbrace{\mathbb{E}_t \left(v_{t+1}^g \,\square\, v_{t+1}\right)}^{\triangle \text{ in value}} \tag{18}$$

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 exporting times the discounted gain from transforming the local good in a global intermediate good.

In the symmetric equilibrium, all producers of local intermediate goods invest the same amount in making the good exportable to S, and, as a result, face the rate of transformation of local into global intermediate goods, λ_t^g. The law of motion for A^g is

$$A_t^g = \phi\lambda_{t-1}^g A_{t-1}^l + \phi(1 \,\square\, \lambda_{t-1}^T)A_{t-1}^g \tag{19}$$

After expanding the market to S, the value of an intermediate good, v_t^g, is given by

$$v_t^g = \max_{x_t^T} \pi_t^g \,\square\, e_t x_t^T + \tag{20}$$
$$R_{Nt}^{-1}\phi\mathbb{E}_t \left[\lambda\left(\Gamma_t^T x_t^T\right) v_{t+1}^T + \left(1 \,\square\, \lambda\left(\Gamma_t^T x_t^T\right)\right) v_{t+1}^g\right],$$

where π_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 by the innovator in transferring the production of the intermediate good to S, e_t is the exchange rate (dollars per peso), $\lambda(\Gamma_t^T x_t^T)$ is the associated probability of successfully completing this foreign direct investment, where the function $\lambda(.)$ satisfies $\lambda' > 0$, $\lambda'' < 0$, v^T is the market value of the company that produces a transferred

intermediate good, and Γ_t^T is a scaling factor, taken as exogenous by the innovator and equal to

$$\Gamma_t^T = \frac{b^T}{(\overline{P}_{Nt}^k K_{Nt}/A_t^g)} \tag{21}$$

where b^T is a positive constant.

Foreign direct investment

Let λ_t^T be the rate at which the production of global intermediate goods is transferred from N to S. The law of motion for the stock of transferred intermediate goods, A_t^T, can be written as follows:

$$A_t^T = \phi \lambda_{t-1}^T A_{t-1}^g + \phi A_{t-1}^T \tag{22}$$

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.

$$e_t = \overbrace{R_{Nt+1}^{-1}\phi}^{\text{discounting}} \overbrace{\Gamma_t^T \lambda' \left(\Gamma_t^T x_t^T\right)}^{\text{Mg. }\triangle\text{ in }\lambda^T} \overbrace{\mathbb{E}_t \left(v_{t+1}^T \ \square \ v_{t+1}^g\right)}^{\triangle\text{ in value}} \tag{23}$$

Finally, the market value of an intermediate good whose production has been transferred to S is given by

$$v_t^T = \pi_t^T + R_{Nt+1}^{-1}\phi E_t v_{t+1}^T, \tag{24}$$

where π_t^T denotes the per period operating global profits of the company that produces a transferred intermediate good.

2.4   Production of gross output

Gross output, Y_{ct}, is produced in two stages. At the first stage, each of N_{ct} differentiated output producers, indexed by j, combine capital, K_{cjt}, labor, L_{cjt}, and energy, E_{cjt}, to produce its differentiated output, $Y_{ct}(j)$ according to the following Cobb-Douglas technology:

$$Y_{ct}(j) = (1+g)^t \left(U_{cjt}K_{cjt}\right)^\alpha E_{cjt}^\eta \left(L_{cjt}\right)^{1-\eta-\alpha} \tag{25}$$

where g is the exogenous growth rate of disembodied productivity,[11] and U denotes the intensity of utilization of capital. The markets where firms rent the factors of production (i.e. labor and

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[11] For simplicity, we assume that it is exogenous. It is quite straightforward to endogenize it as shown in Comin and Gertler (2006).

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:

$$Y_{ct} = [\int_0^{N_{ct}} Y_{ct}(j)^{\frac{1}{\mu}} dj]^{\mu} \tag{26}$$

where $\mu(>1)$ is inversely related to the price elasticity of substitution across goods. Producers of differentiated output must pay every period an overhead cost, o_{ct}, given by

$$o_{ct} = b_c \overline{P}_{ct}^K K_{ct}. \tag{27}$$

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

$$\frac{\mu \ \Box \ 1}{\mu} P_{ct}(j) Y_{ct}(j) = b_c \overline{P}_{ct}^K K_{ct} \tag{28}$$

2.5 Energy endowments

Oil represents a significant share of Mexican exports to the US. 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 to 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:

$$E_{St} = E_{St}^e \ \Box \ E_t^x \tag{29}$$
$$E_{Nt} = E_t^w + E_t^x \tag{30}$$

For simplicity, we assume that the price of energy, P^E, is fixed.

2.6 Households

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. It makes one period loans to innovators and also rents capital that it has accumulated directly to firms. It is important to stress, though, that there is no international lending and borrowing. That is, US FDI in Mexico is the only item in the Mexican financial account.

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Let C_{ct} be consumption and μ_{ct}^w a preference shifter. Then the household maximizes its present discounted utility as given by the following expression:

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

subject to the budget constraint

$$C_{ct} = \omega_{ct} L_{ct} + \Pi_{ct} + [D_{ct} + P_{ct}^k] K_{ct} \ \Box \ P_{ct}^k K_{ct+1} + R_{ct} B_{ct} \ \Box \ B_{ct+1} \ \Box \ T_{ct} \tag{31}$$

where Π_{ct} reflects the profits of monopolistic competitors paid out fully as dividends to households, D_{ct} denotes the rental rate of capital, B_{ct} is the total loans the household makes at $t \ \Box \ 1$ that are payable at t, and T_{ct} reflects lump sum taxes.

Government

Government spending is financed every period with lump sum transfers and the revenues from energy:

$$G_{ct} = T_{ct} + P^E E_{ct}^e \tag{32}$$

3 Symmetric equilibrium

We defer to the Appendix the formal definition and complete characterization of the equilibrium. Here we just present the main equations to highlight the effects of endogenizing the investment decisions that determine the extensive margin of trade and FDI. In a model without these investments, such as Comin and Gertler (2006), capital, K_{ct}, and the stock of intermediate goods, A_{Nt}, are the only endogenous state variables. Here, we have two additional endogenous states, the stock of global intermediate goods, A_t^g, and the stock of transferred intermediate goods, A_t^T which introduce new dynamics in Mexican output and the relative price of capital.

The relevant equations of motion are thus given by (3), (19), (22) and

$$A_{Nt+1} = \chi A_{Nt} \left(\frac{S_t}{\overline{P}_{Nt}^k K_{Nt}} \right)^{\rho} + \phi A_{Nt}. \tag{33}$$

It is convenient to define the variable a_{Nt} as the ratio of the effective number of intermediate good in N relative to A_t^l, and a_{St} as the ratio of the effective number of intermediate goods in

S relative to A_t^T. Formally,

$$a_{Nt} = \left[1 + \frac{A_t^g}{A_t^l} + \frac{A_t^T}{A_t^l} \left(\frac{\psi \xi}{e_t} \right)^{\frac{1}{\theta-1}} \right] \tag{34}$$

$$a_{St} = \left[\frac{A_t^g}{A_t^T} \left(\frac{\psi e_t}{\xi} \right)^{\frac{1}{\theta-1}} + 1 \right] \tag{35}$$

Then, the profits accrued by a producer of local, global and transferred intermediate goods can be expressed respectively as:

$$\pi_t = \left(1 - \frac{1}{\theta} \right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} \tag{36}$$

$$\pi_t^g = \left(1 - \frac{1}{\theta} \right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} + \left(1 - \frac{1}{\theta} \right) e_t \frac{P_{St}^K J_{St}}{\mu_k a_{St} A_t^T} \left(\frac{\psi e_t}{\xi} \right)^{\frac{1}{\theta-1}} \tag{37}$$

$$\pi_t^T = \left(1 - \frac{1}{\theta} \right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} \left(\frac{\psi \xi}{e_t} \right)^{\frac{1}{\theta-1}} + \left(1 - \frac{1}{\theta} \right) e_t \frac{P_{St}^K J_{St}}{\mu_k a_{St} A_t^T} \tag{38}$$

Note that π_t, π_t^g and π_t^T are increasing in country N's investment, while π_t^g and π_t^T also increase with investment in S. Since the value of local, global and transferred intermediate goods, defined in (16), (20) and (24), is equal to the present discounted profits net of investments in exporting and FDI, v, v^g and v^T are also pro-cyclical. The pro-cyclicality of the value of intermediate goods has important implications for the dynamics of productivity.

First, since the costs of conducting R&D are acyclical and v is pro-cyclical, free entry (15) implies that R&D expenditures are pro-cyclical. Second, the capital gains from starting to export intermediate goods (i.e. $v_{t+1}^g - v_{t+1}$) and transferring the production (i.e. $v_{t+1}^T - v_{t+1}^g$) are both pro-cyclical since v^g fluctuates more than v and v^T more than v^g.[12] According to (18) and (23), this implies that the resources devoted to exporting and transferring the production of intermediate goods to S (i.e. x^g and x^T) are pro-cyclical.

The slow pace of international diffusion of technologies implies that A^g and A^T respond slowly to x^g and x^T. This introduces a lag in the response of the level of technology in S to shocks which generates significant medium term fluctuations in Mexican macro variables. In this way, a contractionary shock in N generates an initial decline in $S's$ output due to the

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[12]The first follows because v^g fluctuates in response to current and future investment in both S and N while v only responds to investment in N. The second follows because transferred intermediate goods are cheaper and therefore face higher demand than global intermediate goods.

lower demand for $S's$ exports but also generates a more persistent decline driven by the lower productivity.

Since intermediate goods are the source of embodied technical change, the slow response of A_{St} to shocks generates counter-cyclical fluctuations in the Mexican price of capital over the medium term. introduces important dynamics in the Mexican relative price of capital (39).[13]

$$P_{St}^{K} = \overbrace{\mu^{K}\theta}^{\text{Markups}} \overbrace{\frac{(N_{kSt})^{-(\mu_{kS}-1)}}{\xi}(a_{St}A_{t}^{T})^{-(\theta-1)}}^{\text{Mg. cost of production}} \tag{39}$$

Mexican firms would like to reduce drastically investment precisely when the price of new capital peaks. However, this would be too costly because of the costs of adjusting the flow of investment. Instead, in anticipation of the future higher price of capital, firms start reducing investment when the contractionary shock hits the US economy. This collapse in investment adds to the lower demand for Mexican exports generating a larger initial effect of US shocks in Mexican than in US output. As we shall see, this explains why developing economies are more volatile than their developed neighbors.

In the neoclassical growth model, the interest rate is equal to the marginal product of capital net of depreciation. Since the marginal product of capital is pro-cyclical, so are interest rates. However, Neumeyer and Perri (2005) show that in developing countries interest rates are counter-cyclical. This is the case also in our model because, in addition to the marginal product of capital, interest rates also depend on the increment in the price of installed capital.

$$R_{St} = E_{t}\left[\frac{\frac{\alpha Y_{St}}{\mu K_{St}} + (1 \square \delta(U_{t+1}))P_{St+1}^{I}}{P_{St}^{I}}\right] \tag{40}$$

Recall from the optimal investment equation (10) that the price of installed capital is equal to the price of new capital plus a wedge that reflects changes in investment flows. Thus, the prospects of increases in the price of new capital in response to a contractionary shock, lead to high interest rates today. This effect adds to the standard permanent income effect of output on consumption generating a very significant contraction in consumption in S.

The adjustment costs contribute to making the decline in consumption feasible. In particular, they moderate the initial collapse in Mexican investment following a recessionary domestic

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[13]Short term fluctuations in the relative price of capital are driven by the exchange rate and by pro-cyclical entry.

shock absorbing resources that force Mexican consumption to decline. As we shall see below, these mechanisms can explain why consumption is not less volatile than output in developing countries.

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 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. Twelve appear routinely in other studies. Six relate to the process of innovation and research and development 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 US. We do this for two reasons. First, there is ample evidence on the larger costs of entry, obtaining construction permits and import licenses in Mexico relative to the US (e.g. Gwartney et al., 2007, World Bank, and Miller and Holmes, 2009). Second, above and beyond the micro evidence on adjustment costs, our goal is to build a model of the Mexican economy and its response to US shocks. To achieve this goal, we need to build a model of the US economy that resembles as much as possible the data. As we discuss below, even when we set $\xi_N''(1)$ to zero, our model generates series for

US investment that have less volatility than in the data. Introducing adjustment costs to US investment would accentuate this problem.

There are no estimates, to the best of our knowledge, for ξ_S''. Given that, we think that a conservative estimate is a value in the upper end of the range of estimates for the adjustment cost parameter in the US. We use the estimate of Christiano, Eichenbaum and Evans (2005) and set $\xi_S''(1)$ to 1.5. We also set $\xi_N''(1)$ to 0.

We calibrate the six parameters that govern the interactions between N and S by matching information on trade flows, and US FDI in Mexico and micro evidence on the cost of exporting and the relative productivity of US and Mexico in manufacturing. First, we set ξ to 2 to match the Mexican relative cost advantage over the US in manufacturing identified by Iyer (2005). We set the inverse of the iceberg transport cost parameter, ψ, to 0.95,[14] the steady state probability of exporting an intermediate good, λ^g, to 0.0875, and the steady state probability of transferring the production of an intermediate good to S, λ^T, to 0.0055 to approximately match the share in Mexican GDP of Mexican exports and imports to and from the US (i.e. 18% and 14%, respectively) and the share of intermediate goods produced in the US that are exported to Mexico. Specifically, Bernard, Jensen, Redding and Schott (2007) estimate that approximately 20 percent of US 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 US that are exported. This yields an average diffusion lag to Mexico of 11 years which seems reasonable.

Das, Roberts and Tybout (2006) 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 λ^g with respect to investments in exporting, ρ_g, to 0.85 so that the sunk cost of exporting represents approximately 30 percent of the revenues from exporting. The elasticity of λ^T with respect to FDI expenses, ρ_T, together with the steady state value of λ^T determine the share of US FDI in Mexico in steady state. We set ρ_T to 0.5 so that the US FDI in Mexico represents approximately 2% of Mexican GDP.

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[14]Interestingly, the value of ψ required to match the trade flows between the US and Mexico is smaller than the values used in the literature (i.e. 1/1.2 in Corsetti et al., 2008) because of the closeness of Mexico and the US and their lower (inexistent after 1994) trade barriers.

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 markup, μ_{ct}^w, in N (US) and in S (Mexico). Several authors[15] have argued that these shocks may capture important drivers of business cycles. However, we are not vested in the nature of the shocks. We show that the our conclusions are robust to other shocks (i.e. productivity and relative price of capital).

Response to a US shock

Figure 1 displays the impulse response functions to a US wage markup shock. Solid lines are used for the responses in Mexico while dashed lines represent the responses in the US. The response of the US 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 the US labor supply (panel 2) causing a recession in the US (panel 1). In addition to the decline in hours worked, the initial decline in US output is driven by exit in the final goods sector and by a decline in the utilization rate. The response of US 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 45% of its initial response.

The US shock has important effects on the Mexican economy. Upon impact, the shock causes a decline in Mexican output that is larger than the US contraction (0.63 vs. 0.46). The Mexican recession is driven by two forces: the decline in the demand for Mexican exports to the US (panel 10) and the collapse of Mexican investment (panel 4).

Unlike the US, the response of Mexican output to a US shock is hump-shaped. At the root of this response we find the dynamics of international technology diffusion. In particular, the shock to μ_{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

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[15]E.g. Hall (1997), Gali, Gertler and Lopez-Salido (2002).

diffusion of new technologies also leads to a gradual decline in Mexican productivity which causes a hump-shaped response of output.[16]

Our model generates large fluctuations in Mexican productivity. This is at the root of why US shocks have larger effects on Mexican output than in the US 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 US 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 swims, over the medium term, in the stock of technologies in Mexico. In the US, 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 the Mexican output dynamics, Figure 2 plots the impulse response function to a shock to μ_{Nt}^w after shutting down the extensive margin of trade and FDI channels. When eliminating these linkages between the US and Mexico, the effect of the shock on Mexican output is (i) always smaller than in the US, (ii) monotonic and (iii) significantly less persistent than when these adoption margins are endogenous.

In contrast, in our model, the response of Mexican output to a US shock is more persistent than the US 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 Mexican investment to these prospects for the price of capital largely depends on the magnitude of the adjustment costs. Figure 3 reports the impulse response functions to a contractionary μ_{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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[16]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 US shock generates a collapse of Mexican investment upon impact (panel 4 of Figure 1) 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 US output and Mexican investment.

The response of investment to US shocks significantly amplifies the initial response of Mexican output to the US shock. To see this, compare the output responses with and without adjustment costs (i.e. Figure 1 vs 3). In the absence of adjustment costs, Mexican investment does not decline when the shock hits the economy and the only force that drives the Mexican recession is the decline in demand for Mexican exports to the US. Since the share of exports in Mexican GDP is not that large, Mexican output declines only by 0.05% in response to a 1% increase in μ_{Nt}^w. With adjustment costs, the collapse of investment contributes to the Mexican recession and output declines by 0.66% in response to the same shock. Note however, that in both cases, the decline in Mexican output eventually exceeds the size of the recession generated in the US. Similarly, the hump-shaped response of Mexican output is independent of the calibration of the adjustment costs.

For concreteness, we have used wage markup shocks as the sole source of fluctuations in our model. It is important to stress that our findings do not hinge on the nature of the shock. This is illustrated in Figure 4 where we consider the model's response to other two shocks that play a significant role in the business cycle literature. These are a (negative) TFP shock (second row) and to a (positive) shock to the price of investment (third row).[17] In response to these shocks, the model also generates a large initial decline in Mexican output driven partly by a collapse in investment and a subsequent contraction in productivity due to a decline in the flow of technologies to Mexico.

Response to a Mexican shock

Figure 5 displays the impulse response functions to a Mexican wage markup, μ_{St}^w, shock in the US (dashed) and in Mexico (solid). There are some striking differences with Figure 1. First, a Mexican shock has virtually no effect in the US. This follows from the difference in size between the two economies but also from the fact that technologies flow from the US to Mexico and not otherwise. One consequence of this is that the Mexican shock has a smaller effect than the US shock on the extensive margin of trade and FDI. As a result, the effect of μ_{St}^w on Mexican GDP is more transitory than the effect of a US shock.

However, the most significant observation from Figure 5 is that Mexican shocks have a larger

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[17]Figure A.1 in the appendix, shows the equivalent responses for the model without adjustment costs.

effect on Mexican 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 6.)[18] On the other, they raise current and future interest rates 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 Mexican 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 Mexican 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, π^T, (panel 9). This leads to a very significant decline in FDI inflows into Mexico. (A phenomenon that the "sudden stops" literature (e.g. Calvo 1998) has tried to explain.) To reestablish the international equilibrium, the peso depreciates leading to a trade surplus that absorbs resources, forcing Mexican consumption to fall.[19]

Note that one of the key drivers of the high volatility of consumption in Mexico is the counter-cyclicality of the price of capital. This important prediction is borne by the data. The price of new capital[20] 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.[21] Interestingly, the price of new capital is significantly more counter-cyclical in Mexico than in the US where the equivalent correlation is -0.08.[22] This may explain why consumption is as volatile as GDP in Mexico but

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[18]Adjustment costs smooth the initial response of Mexican 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 FDI to Mexico. As a result, the price of capital in Mexico fluctuates more genarating a larger appreciation in the Mexican price of capital which leads to higher interest rates in response to the shock.

[19]The strong counter-cyclical current account is documented by Neumeyer and Perri (2005) in a sample of developing countries (which includes Mexico).

[20]This is measured by the investment deflator over the GDP deflator.

[21]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.

[22]Over the medium term cycle the correlation between the Mexican price of capital and GDP is -0.71. In

not in the US.

Comparing Figures 1 and 5, it is clear that the high relative volatility of consumption in Mexico is driven by Mexican shocks rather than by US shocks. This is the case because Mexican shocks have a much larger effect on Mexican interest rates than US shocks. Intuitively, US shocks trigger a more persistent decline in Mexican 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).[23] Hence, the lower increase in interest rates following a recessionary shock in the US vs. Mexico.

Before moving on to the quantitative analysis of the model it is worthwhile making a remark about the relative volatility of consumption and output in the US. Note that, according to Figure 3, consumption is more volatile than output in the model. This is a counter-factual prediction that follows from the assumption that the US only trades with Mexico. This assumption implies that the price of capital in the US increases very gradually in response to a decline in FDI to Mexico. (Recall that transferring the production of intermediate goods reduces their price in the US.) As argued above, the prospect of a higher future price of capital in the US reduces the decline in current investment and increases current and future interest rates leading to a larger decline in US consumption.

In reality, the US imports a large share of its intermediate goods from many countries in addition to Mexico including many developed economies that do not obtain their intermediate goods only from the US. As a result, the actual number of intermediate goods imported by the US is more independent from US shocks than in the model and the price of capital in the US increases less gradually than in Figure 3. This intuition is illustrated in Figure A2 were we present the impulse responses (to the three types of shocks) of the version of the model without the international diffusion of intermediate goods. In this extreme case where US shocks do not affect the technology available for production in other countries, the initial response of investment is much more pronounced than in Figure 3 and the response of the US price of capital is less gradual. This results in a consumption process that is less volatile than US

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the US, the correlation between these variables over the medium term is -0.55. For the full post-war period the correlations in the US are slightly larger (in absolute value). -0.18 for HP-filtered data and -0.66 over the medium term.

[23] A decline in investment leads to an increase in the price of installed capital because the adjustment costs embedded in (3) imply that lower levels of investment today increase the costs of investment tomorrow.

output.[24]

Next, we look at the Mexican post-1990 data as a case study to evaluate the predictions of our model.

4.3 Mexico 1990-2007[25]

As in many other developing economies,[26] Mexican output is more volatile than that of the US. Table 1 reports the standard deviation of GDP per working age person[27] at the business cycle (or high) frequency (first column) and over the medium term cycle (third column) for the US (row 10) and Mexico (row 1).[28] Mexico's output fluctuations at high and medium term frequencies are approximately twice more volatile than those of the US.

Our model predicts that an important factor contributing to the higher volatility of the Mexican economy is that Mexican GDP responds significantly to US shocks while the US does not respond much to Mexican shocks. To explore these predictions Figure 7A plots US and Mexican GDP filtered using an HP filter to capture the high frequency (i.e. business cycle) fluctuations. The correlation coefficient between the two is 0.43 and, despite the short length of the series, it is significant at the 10% level. Beyond this statistic, the internet-driven expansion in the US during the second half of the 90s was accompanied by a similar expansion in Mexico. The 2001 US recession driven by the burst of the dot-com bubble also coincided with a decline in Mexican GDP that quickly recovered following the US expansion between 2002 and 2007. Finally, the US financial crisis of 2008 also had a strong impact in Mexican GDP though this

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[24]This is also the case in the single-country model of Comin and Gertler (2006) where the volatility of consumption and output match the US data.

[25]We restrict our attention to the post 1990 period for two reasons. First, the volume of US-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 the model's assumptions about the capital markets most appropriate for this period.

[26]See, for example, Neumeyer and Perri (2005).

[27]In what follows we scale all variables by working age population, i.e. population aged between 16 and 64.

[28]To be precise, we follow the definitions of medium term used by Comin and Gertler (2006). In particular, the sort run or high frequency will be measured using an HP filter which roughly isolates frequencies associates with cycles of amplitude smaller than 8 years. The medium term refers to frequencies associated with cycles of amplitude between 8 and 50 years. The medium term cycle is the "sum" of the high frequency and the medium term. That is, it captures cycles with amplitude smaller than 50 years. Comin and Gertler (2006) show that despite the relatively short time series, medium term cycles can be identified in the data quite precisely.

did not show yet in 2008 average annual output.[29]

It seems reasonable to argue that none of these shocks had a direct effect on the Mexican economy and, therefore, the co-movement with US GDP resulted from the international transmission of US fluctuations. The only important Mexican shock over this period was the 1995 recession which, despite its virulence, was relatively short-lived and had no effect on the US. These observations are consistent with our model predictions that domestic shocks to S have less persistent consequences in S than shocks to N, and have virtually no effect on N.

The model also predicts that US shocks should have an effect on medium term fluctuations in Mexico and that this effect should be strongest with a lag. The first row of Table 3 reports the correlation between HP-filtered US GDP at various lags and the medium term component of Mexican GDP. Specifically, the contemporaneous correlation is 0.28 and increases to 0.49 after a year and to 0.53 after two. Despite the short length of the series, the lagged correlation coefficients are significantly different from 0 at conventional levels.

To obtain a better understanding of the data that underlies this co-movement pattern, Figure 7B plots the medium term component of Mexican GDP together with HP-filtered US 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 Mexican GDP, the latter strongly recovered with the US post-1995 expansion. The Mexican recovery lagged the US boom by about two years. The end of the Mexican expansion also lagged the end of the US expansion by one year. Finally, the post-2001 US expansion also coincided with a boom in the medium term component of Mexican GDP.

In contrast, the cross-correlogram between HP-filtered Mexican GDP and the medium term component of Mexican GDP (row 3) monotonically declines after the maximum correlation that occurs contemporaneously.[30]

To conclude this brief case study, we explore whether the margins that generate the co-movement in our model are also pro-cyclical in the data. Table 2 shows that bilateral trade flows between the US and Mexico are pro-cyclical. The table also reports the cyclicality of

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[29]Between 2007:IV and 2008:IV Mexican real GDP declined by 1.75%. In contrast, annual GDP increased by 1.4% between 2007 and 2008.

[30]Figures A3 and A4 show similar co-movement patterns when using VAR methods to identify high frequency innovations to US and Mexican GDP. Specifically, we identify US shocks and Mexican shocks by running bivariate VARs under the identification restriction that innovations to US GDP may affect Mexico contemporaneously but innovations to Mexican GDP (or any other Mexican variable) do not affect the US contemporaneously.

two measures of the increment in the number of intermediate goods exported from the US to Mexico. Namely, the growth rate of the number of 6-digit classification codes in manufacturing and in durable manufacturing in which the volume of exports from the US to Mexico is larger than $1 million in a given year. These measures of the extensive margin of trade vary also pro-cyclically with both US and Mexican GDPs. Finally, Table 2 reports a positive (though insignificant) co-movement between US FDI to Mexico (as a share of Mexican GDP) and both US and Mexican GDP. Reassuringly, this co-movement becomes statistically significant when we remove some noise from the FDI series by filtering it to keep the medium term fluctuations.

4.4 Simulations

After showing that, qualitatively, our model is consistent with the main patterns in the data we next explore its ability to account for them quantitatively. To this end, we calibrate the volatility and persistence of wage markups shocks in the US and Mexico and run 1000 simulations over a 17-year long horizon each. Specifically, we impose the same autocorrelation for the wage markups in both Mexico and the US (0.6 annually) to reflect our view that much of the difference in the persistence of the "reduced form" shocks that hit the two economies arises from the endogenous international diffusion of technologies.[31]

We calibrate the volatility of the shocks by forcing the model to match the high frequency standard deviation of GDP in Mexico and the US. This yields a volatility of the wage markup shock of 3.76% in the US and 4.97% in Mexico. Note that this significantly higher volatility of the Mexican shock is consistent with the view that developing economies suffer larger shocks than developed neighbors. Below we explore whether the higher volatility of the shocks is a significant factor in explaining the higher GDP volatility in developing economies.

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 US at the high frequency. In addition, the model

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[31]We borrow this value from Comin and Gertler (2006) that estimate that this is the required autocorrelation to match the persistence of the US total markup (i.e. the sum of the price and wage markup). Note that, because of the propagation obtained from the endogenous technology mechanisms, this class of models require 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.

also matches the observed volatility of output over the medium term both in Mexico (0.038 vs. 0.037 in the data) and in the US (0.02 vs. 0.015 in the data). Note that there is nothing in our calibration strategy that forces the model to matching the variance of output at lower frequencies. Matching these moments implies 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 consumption in Mexico both at the high frequency (0.03 vs. 0.031 in the data) and over the medium term cycle (0.038 vs. 0.04 in the data). This is of special interest given the attention that the international macro literature has given to these moments.

It also generates series for investment, the relative price of capital, bilateral trade flows, the extensive margin of trade and FDI flows that on average have similar volatilities to those observed in the data. For those instances where there is some differences, the empirical volatilities fall within the 95% confidence interval for the standard deviation of the simulated series.[32]

Co-movement

Table 2 reports the contemporaneous correlation between the HP-filtered Mexican variables and HP-filtered output in both Mexico and the US. Broadly speaking, the model does a very good job in capturing the contemporaneous co-movement patterns both within Mexico but also between Mexico and the US. First, the model generates the strong co-movement between US and Mexican GDPs observed in the data. Specifically, the average correlation between these variables in our simulations is 0.71 with a confidence interval of (0.4 , 0.9) that contains the correlation observed in the data (i.e. 0.43).

Second, the model generates the observed correlation between consumption and output in Mexico (0.76 vs. 0.78 in the data). Note also that, in both model and data, Mexican consumption is insignificantly correlated with US GDP. This indicates that US shocks do not contribute to the high volatility of Mexican consumption. This instead is the result of the response of Mexican consumption to domestic shocks.

A key driver of the volatility of consumption are the dynamics of the price of capital induced by domestic shocks. It is reassuring that the model matches closely the negative co-movement between Mexican output and the price of new capital (-0.45 vs. -0.54 in the data). Note also

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[32]Note that the model also underpredicts the volatility of the extensive margin of trade, though given the distance between the measure in the model and in the data that should not be a surprise. Note also that, as discussed in section 4.2, the model generates a process for US consumption that is too volatile.

that the model generates an insignificant contemporaneous co-movement between the price of capital in Mexico and US GDP which is also consistent with the evidence (-0.13 in model vs. 0.13 in data). This is the case because, as we shall see below, US shocks affect the price of new capital over the medium term but not so much contemporaneously.

Recall that the strong co-movement between US output and Mexican investment is the key driver of the large effect that US shocks have on Mexican GDP. The model matches very closely the observed strong co-movement between Mexican investment and output in both the US (0.69 vs. 0.6 in the data) and Mexico (0.77 vs. 0.62 in the data).

Similarly, recall that the medium term productivity dynamics in Mexico result from the cyclicality of the flow of intermediate goods that become exportable to Mexico (i.e. the extensive margin of trade). The model matches quite closely the co-movement between the growth in the number of varieties exported to Mexico (specially in durable manufacturing) and output in both the US (0.42 vs. 0.28 in the data) and in Mexico (0.42 vs. 0.42 in the data).

The model also broadly captures the cyclicality of the bilateral trade flows which are also partly responsible for the co-movement between the US and Mexican GDPs. In particular the model captures the fact that Mexican imports from the US co-move more with Mexican GDP (0.82 vs. 0.93 in the data) than Mexican exports to the US (0.59 vs. 0.08 in the data). The model is also consistent with the strong co-movement of US GDP and both Mexican imports from the US (0.81 vs. 0.61 in the data) and exports to the US (0.56 vs. 0.68 in the data). Interestingly, .

Finally, the model captures the strong counter-cyclicality of Mexican trade balance. Specifically, the correlation between the Mexican trade balance as a share of GDP is -0.98 vs. -0.83 in the data. The model is also consistent with the higher (in absolute terms) correlation of the Mexican trade balance with Mexican GDP than with US GDP (-0.74 vs. 0.07 in the data).[33] It however generates FDI flows that are too cyclical maybe because of the presence of a small but volatile component in actual FDI that does not respond to the US or Mexican business cycle.

Inter-frequency co-movement

A final fact presented in section 4.3 is the lead of US output over medium term fluctuations in Mexico. Table 3 explores the model's ability to capture this fact. The first row reports the empirical correlation between lagged HP-filtered US output and the medium term component of Mexican output. The second row reports the average cross-correlation across 1000 simulations

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[33]The higher counter-cyclicality of the Mexican trade balance with respect to US GDP in the model than in the data surely results from the lack of other international shocks.

of the model. The model roughly captures the contemporaneous correlation between high frequency fluctuations in US output and medium term fluctuations in Mexican output (0.38 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 (0.45).

A key prediction of our model is that the high frequency response of the extensive margin of trade to US shocks generates counter-cyclical fluctuations in the relative price of capital in Mexico over the medium term. The fourth row in Table 3 presents a quantitative evaluation of this prediction where we report the average correlation across our 1000 simulations between the medium term component of the Mexican relative price of capital and HP-filtered US output at various lags. The correlation becomes more negative as we lag US GDP reaching a peak (in absolute terms) after two years (-0.42). This co-movement pattern matches quite closely the actual co-movement in the data reported in the third row of Table 3. There we can also see that the correlation between US GDP and the medium term component of the relative price of capital in Mexico gradually becomes more negative as we lag US GDP. The peak in reached at -0.5 with a 3-year lag of US GDP over the Mexican price of capital.

Mexican and US shocks have a different effect on Mexican medium term fluctuations. Row 5 in Table 3 reports the actual correlation between HP-filtered Mexican output at various lags and the medium term component of Mexican output. Though the contemporaneous correlation is positive it declines monotonically as we lag the series of HP-filtered output.[34] Our model is consistent with this co-movement pattern since, unlike US shocks, Mexican shocks in our model do not induce a hump-shaped response of Mexican output (Figure 5). This is illustrated in row 6 of Table 3. The contemporaneous correlation between HP-filtered and medium term Mexican GDP is 0.6 (vs. 0.45 in the data) and it becomes insignificant when lagging HP-filtered GDP by two years (vs. one in the data).

Finally, in both, the model and the data (rows 7 and 8 in Table 3), we observe similar co-movement pattern between HP-filtered Mexican GDP and the medium term component of the Mexican price of capital. In both we observe that the counter-cyclicality of the medium term component of the price of capital in Mexico increases as we increased the lag reaching a peak of -0.34 after 2 years in the data vs. -0.52 after one year in the model.

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[34]In table A4, we make a similar point by estimating VARs with HP-filtered Mexican GDP and the medium term component of several Mexican variables (including GDP).

Implications for Aggregate Volatility

It is clear from Figure 1 that US shocks are a significant source of volatility in Mexican GDP. But, what share of Mexican fluctuations is due to US shocks and what share is due to domestic shocks? Similarly, how much do Mexican shocks contribute to the volatility of US GDP?

Table 4 answers these questions by reporting the share of output volatility in each country attributable to each kind of shocks. 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 US fluctuations (3% at high frequency and 2% over the medium term cycle).

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

5   Conclusions

We have developed a two country asymmetric model to study the business cycle in developing countries. The model has two distinct elements for which we have plenty of micro evidence: the endogenous and slow diffusion of technologies from the developed to the developing country and the presence of flow adjustment costs to investment in the developing economy. When calibrated to the Mexican economy, our model generates three important features of Mexican business cycles.

First, US shocks have a larger effect on Mexican than on US GDP. This result is driven by the larger amplitude of fluctuations in Mexican productivity and by the effects that this has on investment. This finding has important implications for the sources of Mexican volatility. Despite the higher volatility of Mexican shocks, the differential in GDP volatility between US and Mexico is due to the magnitude of the Mexican response to US shocks.

Second, the slow diffusion of technologies to Mexico generates a hump-shaped response in Mexican output in response to US shocks. As a result, US shocks have more persistent effects on Mexico than in the US. Further, this explains the observed lead of US GDP over the medium term component of Mexican output and the relative price of capital.

Third, consumption is no less volatile than output in Mexico. Our model accounts for this

stylized fact because a Mexican recession slows down the diffusion of technologies to Mexico, generating a gradual increase in the price of installed capital. As a result, Mexican interest rates increase despite the lower marginal product of capital and consumption drops precipitously.

Of course to study how the extensive margin of trade and FDI respond to US shocks, it is necessary to model both the US and the Mexican economy. The complexity that entails developing a two country model of business cycles with endogenous technology is not trivial. However, by doing that we have not only been able to match the three stylized facts described above but have provided a quantitatively accurate account of high and medium term fluctuations in Mexico. A reasonable educated guess is that the mechanisms introduced in our model should provide an accurate account of business cycles in other developing countries.

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A Symmetric equilibrium

This section describes the complete set of equations that determine the symmetric equilibrium. A symmetric equilibrium in this economy is defined as an exogenous stochastic sequence, $\{\mu_{Nt}^w, \mu_{St}^w\}_{t=0}^\infty$, an initial vector $\{A_{N0}, A_0^g, A_0^T. K_{N0}, K_{S0}\}$, a sequence of parameters, a sequence of endogenous variables $\{P_{ct}^K, \bar{P}_{ct}^K, Y_{ct}, L_{ct}, C_{ct}, I_{ct}, E_{ct}, N_{ct}, N_{ct}^K, S_t, x_t^g, \Lambda_{c,t+1}, x_t^T, v_{t+1}, v_{t+1}^g, v_{t+1}^T, \pi_t, $ for $c = \{N, S\}$, and state variables $\{A_{Nt+1}, A_{t+1}^g, A_{t+1}^T\}_{t=0}^\infty$ such that,

- The state variables $\{A_{Nt+1}, A_{t+1}^g, A_{t+1}^T, K_{Nt+1}, K_{St+1}\}_{t=0}^\infty$ satisfy the laws of motion in the equations (3), (19), (22) and (33).

- The endogenous variables solve the producers and consumers problems in equations (48) through (69).

- Feasibility is satisfied in (41), (42) and (43)

- Prices are such that market clears.

The equilibrium relations of this model are:

Resource constraint in N and S :

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

$$\underbrace{\phantom{\frac{P_{Nt}^K J_{Nt}}{\mu^K \theta a_{Nt}}(1 + \frac{A_t^g}{A_t^l}) + e_t \frac{P_{St}^K J_{St}}{\mu^K \theta a_{St}} \frac{A_t^g}{A_t^T} \left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}}}}_{\text{production of investment goods}} \tag{41}$$

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

$$\underbrace{\phantom{\frac{P_{Nt}^K J_{Nt}}{e_t \mu^K \theta a_{Nt}} \frac{A_t^T}{A_t^l} \left(\frac{\psi \xi}{e_t}\right)^{\frac{1}{\theta-1}} + \frac{P_{St}^K J_{St}}{\mu^K \theta a_{St}} \xi^{\frac{1}{\theta-1}}}}_{\text{production of investment goods}} \tag{42}$$

Aggregate production in N and S :

$$Y_{ct} = \sigma_{ct} N_{ct}^{\mu-1} (U_{ct} K_{ct})^{\alpha} L_{ct}^{1-\alpha} \tag{43}$$

where σ_{ct} is a TFP shock.

Evolution of endogenous states, K_{ct}, A_{Nt}, A_t^g and A_t^T :

$$K_{ct+1} = (1 \square \delta(U_{ct})) K_{ct} + J_{ct} \tag{44}$$

$$A_{Nt+1} = \chi A_{Nt} \left(\frac{S_t}{\overline{P}_{Nt}^k K_{Nt}} \right)^{\rho} + \phi A_{Nt}. \tag{45}$$

$$A_t^T = \phi \lambda_{t-1}^T A_{t-1}^g + \phi A_{t-1}^T \tag{46}$$

$$A_t^g = \phi \lambda_{t-1}^g A_{t-1}^l + \phi (1 \square \lambda_{t-1}^T) A_{t-1}^g \tag{47}$$

$$A_t^l = A_{Nt} \square A_t^g \square A_t^T$$

Optimal factor demand:

$$(1 \square \alpha \square \eta) \frac{Y_{ct}}{L_{ct}} = \mu w_{ct} \tag{48}$$

$$\alpha \frac{Y_{ct}}{U_{ct}} = \mu \delta'(U_{ct}) P_{ct}^I K_{ct} \tag{49}$$

$$\eta \frac{Y_{ct}}{E_{ct}} = \mu P_{ct}^E, \text{ where } P_{Nt}^E = P_t^E, \ P_{St}^E = \frac{P_t^E}{e_t} \tag{50}$$

Labor market equilibrium:

$$(1 \square \alpha \square \eta) \frac{Y_{ct}}{L_{ct}} = \mu \mu_{ct}^w L_{ct}^{\zeta} C_{ct} \tag{51}$$

Consumption/Savings:

$$E_t \left\{ \beta \Lambda_{c,t+1} \frac{\left[\alpha \frac{Y_{ct}}{\mu K_{ct+1}} + (1 \square \delta(U_{ct+1})) P_{ct+1}^I \right]}{P_{ct}^I} \right\} = 1 \tag{52}$$

where

$$\Lambda_{c,t+1} = C_{ct}/C_{ct+1} \tag{53}$$

Optimal investment

$$
\begin{aligned}
P_{ct}^K &= P_{ct}^I \left[1 - \xi_c \left(\frac{J_{ct}}{J_{ct-1}\left(1+g_K\right)} \right) - \xi_c' \left(\frac{J_{ct}}{J_{ct-1}\left(1+g_K\right)} \right) \frac{J_{ct}}{J_{ct-1}\left(1+g_K\right)} \right] \\
&\quad + E_t \left[P_{ct+1}^I \beta \Lambda_{c,t+1} \xi' \left(\frac{J_{ct+1}}{J_{ct}\left(1+g_K\right)} \right) \left(\frac{J_{ct+1}}{J_{ct}\left(1+g_K\right)} \right)^2 \right]
\end{aligned}
\tag{54}
$$

Profits for producers of local, global and transferred intermediate goods:

Let

$$a_{Nt} = \left[1 + \frac{A_t^g}{A_t^l} + \frac{A_t^T}{A_t^l} \left(\frac{\psi\xi}{e_t} \right)^{\frac{1}{\theta-1}} \right] \tag{55}$$

$$a_{St} = \left[\frac{A_t^g}{A_t^T} \left(\frac{\psi e_t}{\xi} \right)^{\frac{1}{\theta-1}} + 1 \right] \tag{56}$$

$$\pi_t = \left(1 - \frac{1}{\theta} \right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} \tag{57}$$

$$\pi_t^g = \left(1 - \frac{1}{\theta} \right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} + \left(1 - \frac{1}{\theta} \right) e_t \frac{P_{St}^K J_{St}}{\mu_k a_{St} A_t^T} \left(\frac{\psi e_t}{\xi} \right)^{\frac{1}{\theta-1}} \tag{58}$$

$$\pi_t^T = \left(1 - \frac{1}{\theta} \right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} \left(\frac{\psi\xi}{e_t} \right)^{\frac{1}{\theta-1}} + \left(1 - \frac{1}{\theta} \right) e_t \frac{P_{St}^K J_{St}}{\mu_k a_{St} A_t^T} \tag{59}$$

Market value of firms that produce local, global and transferred intermediate goods:

$$v_t = \pi_t - x_t^g + R_{Nt}^{-1} \phi \mathbb{E}_t \left[\lambda \left(\Gamma_t^g x_t^g \right) v_{t+1}^g + \left(1 - \lambda \left(\Gamma_t^g x_t^g \right) \right) v_{t+1} \right], \tag{60}$$

where

$$\Gamma_t^g = \frac{b^g}{\left(\overline{P}_{Nt}^k K_{Nt}/A_t^l \right)} \tag{61}$$

$$
\begin{aligned}
v_t^g &= \max_{x_t^T} \pi_t^g - e_t x_t^T + \\
&\quad R_{Nt}^{-1} \phi \mathbb{E}_t \left[\lambda \left(\Gamma_t^T x_t^T \right) v_{t+1}^T + \left(1 - \lambda \left(\Gamma_t^T x_t^T \right) \right) v_{t+1}^g \right],
\end{aligned}
\tag{62}
$$

36

where

$$\Gamma_t^T = \frac{b^T}{\left(\overline{P}_{Nt}^k K_{Nt}/A_t^g\right)} \tag{63}$$

and

$$v_t^T = \pi_t^T + R_{Nt+1}^{-1}\phi E_t v_{t+1}^T, \tag{64}$$

Optimal development and diffusion of intermediate goods:

$$S_t = \phi R_{Nt}^{-1}\mathbb{E}_t v_{t+1}(A_{t+1} \,\square\, \phi A_t) \tag{65}$$

$$1 = R_{Rt+1}^{-1}\phi\Gamma_t^g\lambda'\left(\Gamma_t^g x_t^g\right)\mathbb{E}_t\left(v_{t+1}^g \,\square\, v_{t+1}\right) \tag{66}$$

$$e_t = R_{Nt+1}^{-1}\phi\Gamma_t^T\lambda'\left(\Gamma_t^T x_t^T\right)\mathbb{E}_t\left(v_{t+1}^T \,\square\, v_{t+1}^g\right) \tag{67}$$

Free entry:

$$\frac{\mu \,\square\, 1}{\mu}\frac{Y_{ct}}{N_{ct}} = b_c\overline{P}_{ct}^K K_{ct} \tag{68}$$

$$\frac{\mu^K \,\square\, 1}{\mu^K}\frac{P_{ct}J_{ct}}{N_{ct}^K} = b_c^k\overline{P}_{ct}^K K_{ct} \tag{69}$$

Relative price of capital and wholesale capital:

$$P_{Nt}^K = \iota_{Nt}\mu^K\theta N_{kNt}^{-(\mu_{kN}-1)}(a_{Nt}A_t^l)^{-(\theta-1)} \tag{70}$$

$$P_{St}^K = \iota_{St}\mu^K\theta\frac{(N_{kSt})^{-(\mu_{kS}-1)}}{\xi}(a_{St}A_t^T)^{-(\theta-1)} \tag{71}$$

where ι_{ct} is a shock to the price of capital in country c.

$$\bar{P}_{ct}^K = (A_{ct})^{-(\theta-1)} \tag{72}$$

International equilibrium:

$$\underbrace{\overbrace{\underbrace{\frac{Q_{Nt}J_{Nt}A_t^T}{\mu_{kNt}a_{Nt}A_t^l}\left(\frac{\psi\xi}{e_t}\right)^{\frac{1}{\theta-1}} + P_t^E E_t^x \,\square\, \frac{e_tQ_{St}J_{St}A_t^g}{\mu_{kSt}a_{St}A_{St}^T}\left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}}}_{S's \text{ Trade balance}} \,\square\, \Pi_t^T}_{S's \text{ Net income}}}^{\text{Current account balance in } S} = \square \quad \overbrace{e_t X_t^T}^{S's \text{ financial account balance}} \tag{73}$$

<div align="center">37</div>

The exogenous variables, $\{\mu_{ct}^w,\ \sigma_{ct},\ \iota_{ct}\}$ follow AR(1) processes.

B   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 β 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 number: (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 ζ at unity, which represents an intermediate value for the range of estimates across the micro and macro literature. Similarly, we set the elasticity the change in the depreciation rate with respect 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 valued added markup in the consumption goods sector, μ^c equal to 1.1 and the corresponding markup for the capital goods sector, μ^k at 1.15.

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

We next turn to the "non-standard" parameters. The estimates for the obsolescence rate have 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 ϕ 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, χ. Accordingly, we set: $g = 0.0072$ and $\chi = 2.69$.

There is no direct evidence on the gross markup ϑ 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, ρ. 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 ϑ, ϕ, χ and ρ yield a R&D share in US GDP of approximately 1 percent which is in line with the average of private R&D expenditures in the investment goods sector over GDP over the period 1960-2006.

The value of the Mexican oil production $P^E E_S$ is set to to match the share of Mexican oil exports in GDP. The elasticity of gross output with respect to oil (η) is set to 1.5% following the calculations in Blanchard and Gali (2007).

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.

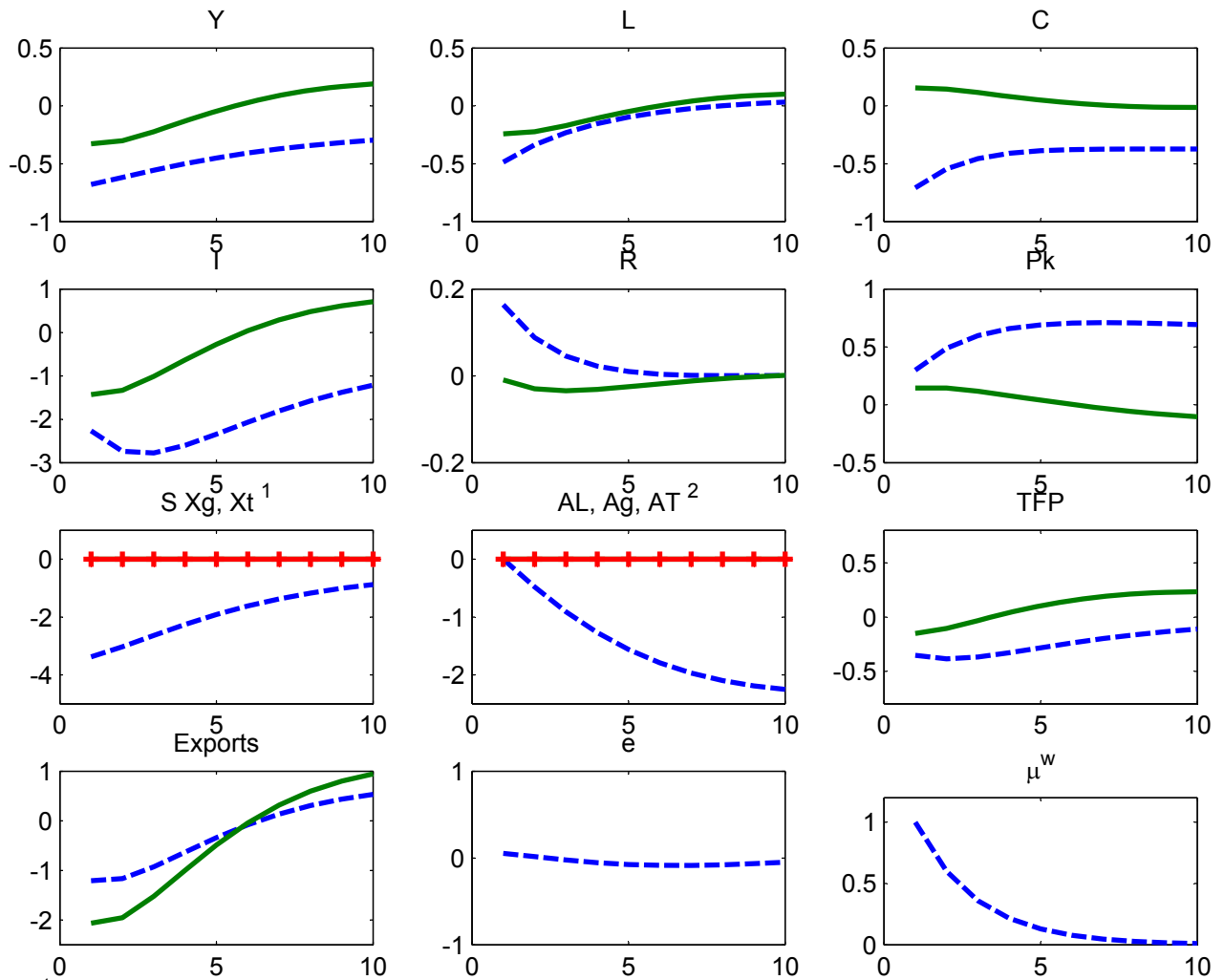Figure 1: IR to a U.S. Markup Shock in Baseline Model. (US dash, Mexico solid)
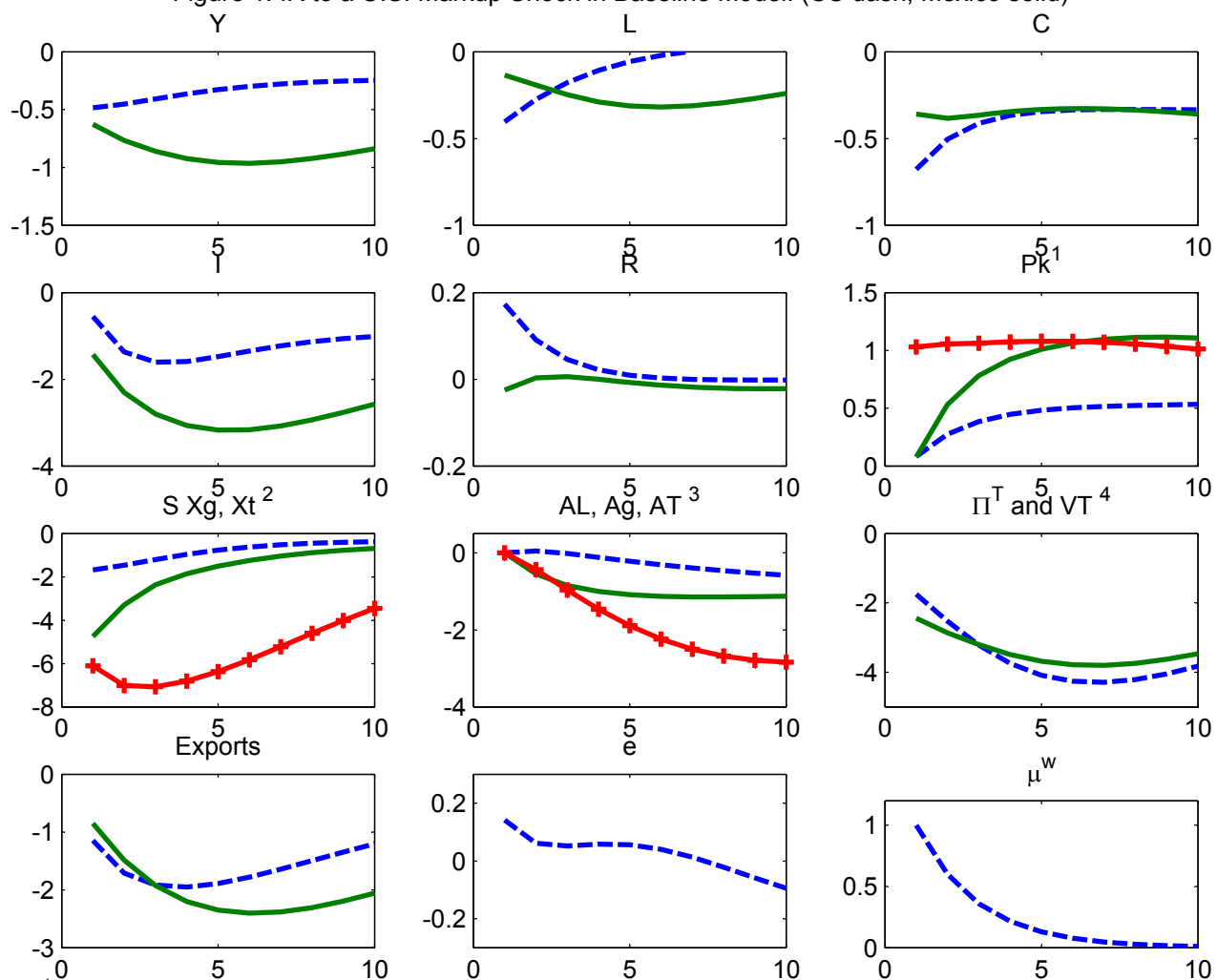
[1] Price of installed capital in Mexico (+)
[2] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)
[3] Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transfered Intermediate Goods(AT,-+)
[4] Net income from transferred intermediate goods (--), Value of transferred intermediate goods (-)
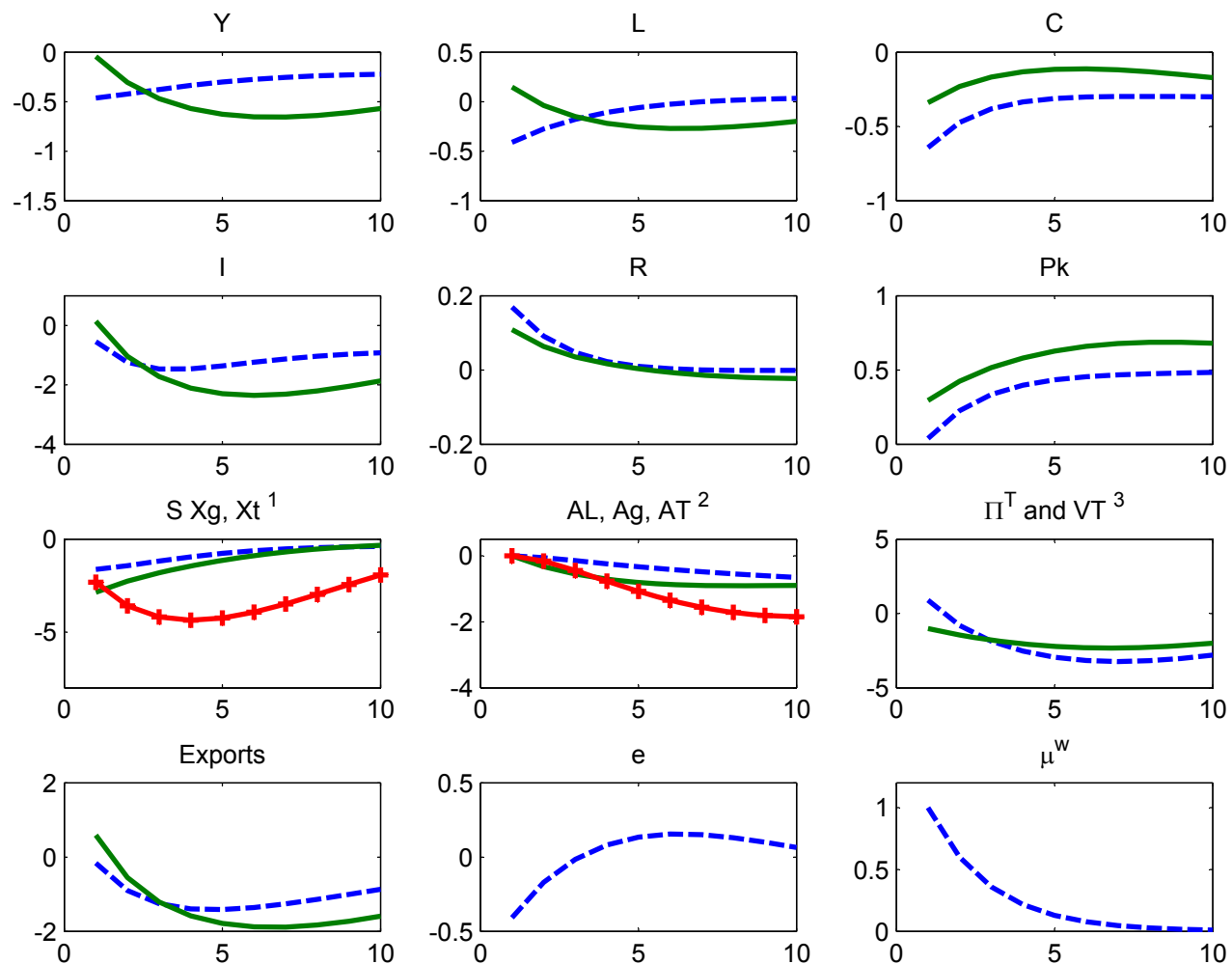
Figure 2: IR to a U.S. Markup Shock in Model without International Technology Flows. (US dash, Mexico solid)

[1] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)

[2] Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transfered Intermediate Goods(AT,-+)

Figure 3: IR to a U.S. Markup Shock in Model without Adjustment Costs. (US dash, Mexico solid)

[1] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)

[2] Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transfered Intermediate Goods(AT,-+)

[3] Net income from transferred intermediate goods (--), Value of transferred intermediate goods (-)

Figure 4: IR to Shocks to Markup, TFP and Price of Investment in the U.S. in Óæ•^|ą̦^ÁModel
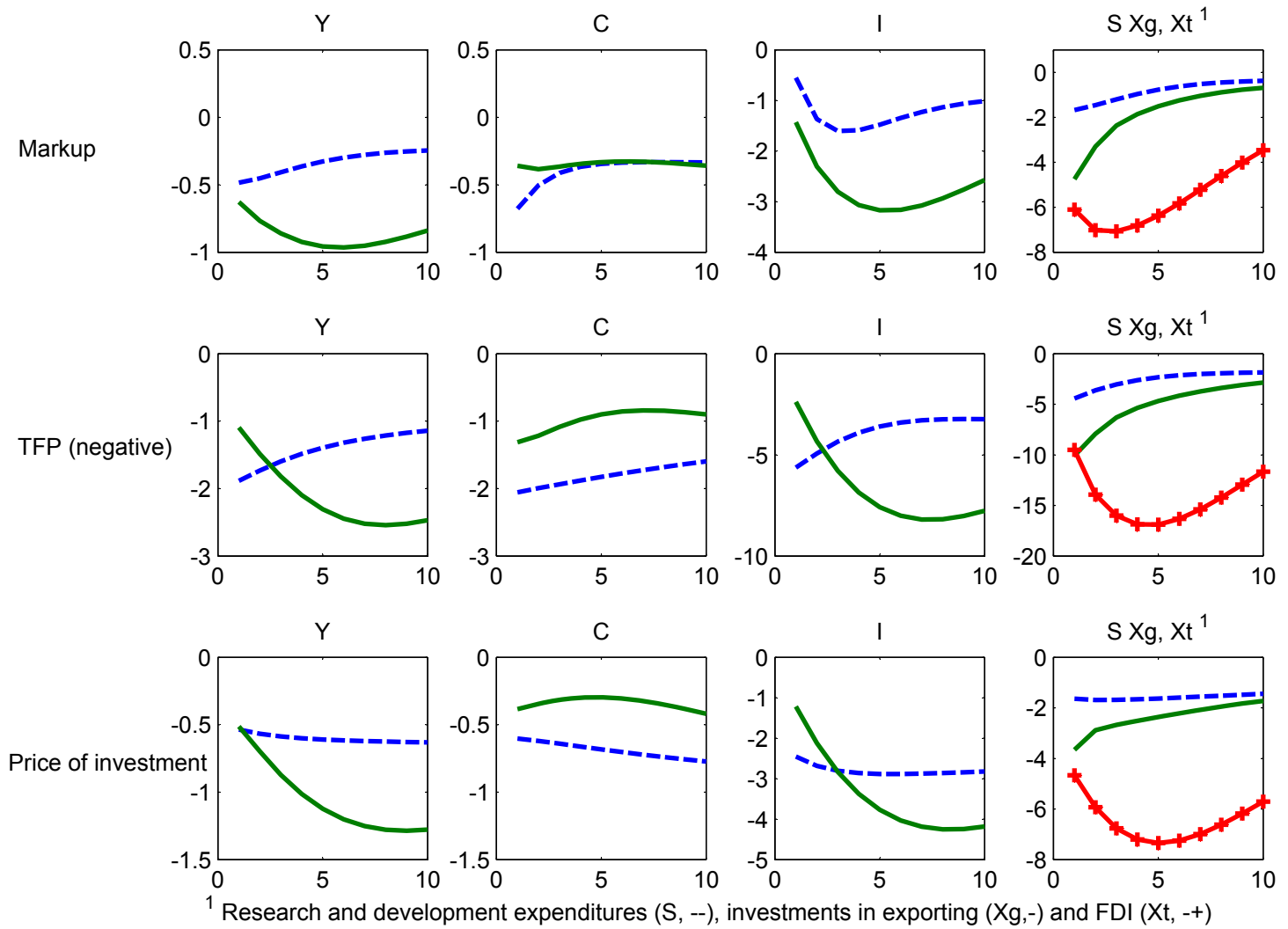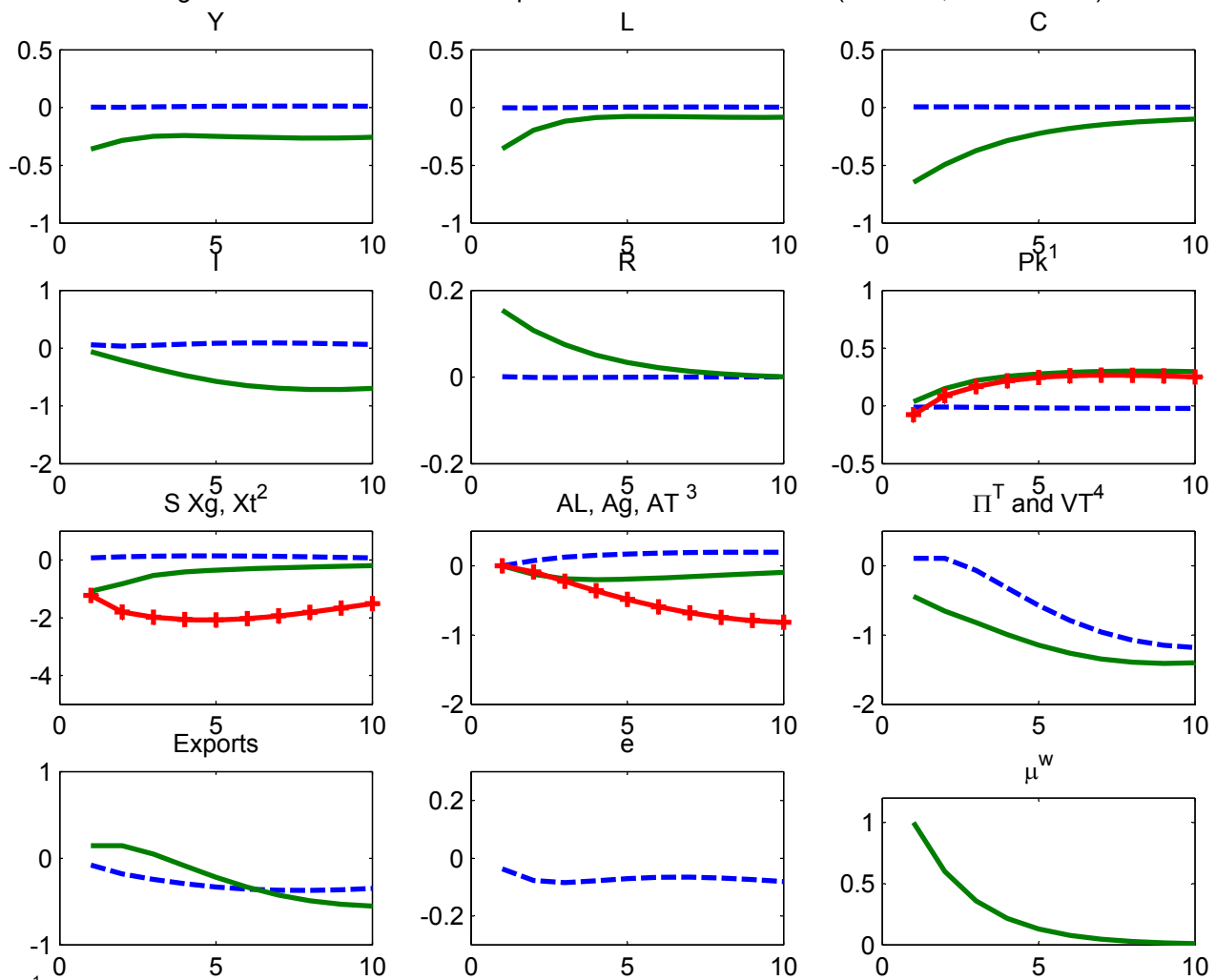
Figure 5: IR to a Mexican Markup Shock in Baseline Model. (US dash, Mexico solid)
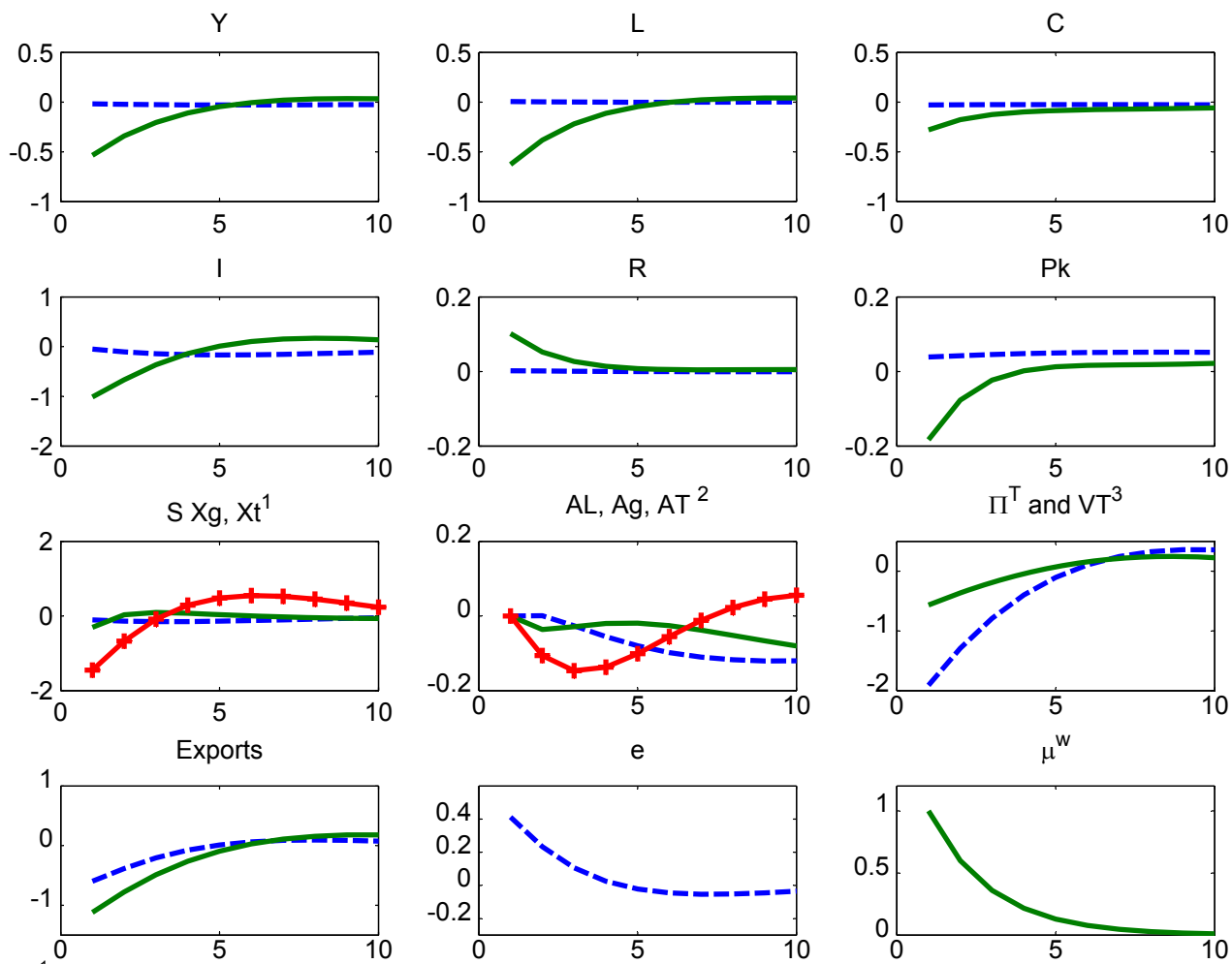
[1] Price of installed capital in Mexico (+)
[2] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)
[3] Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transfered Intermediate Goods(AT,-+)
[4] Net income from transferred intermediate goods (Π^T, --), Value of transferred intermediate goods (VT,-)

Figure 6: IR to a Mexican Markup Shock in Model without Adjustment Costs . (US dash, Mexico solid)

[1] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)

[2] Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transfered Intermediate Goods(AT,-+)

[3] Net income from transferred intermediate goods (Π^T, --), Value of transferred intermediate goods (VT,-)
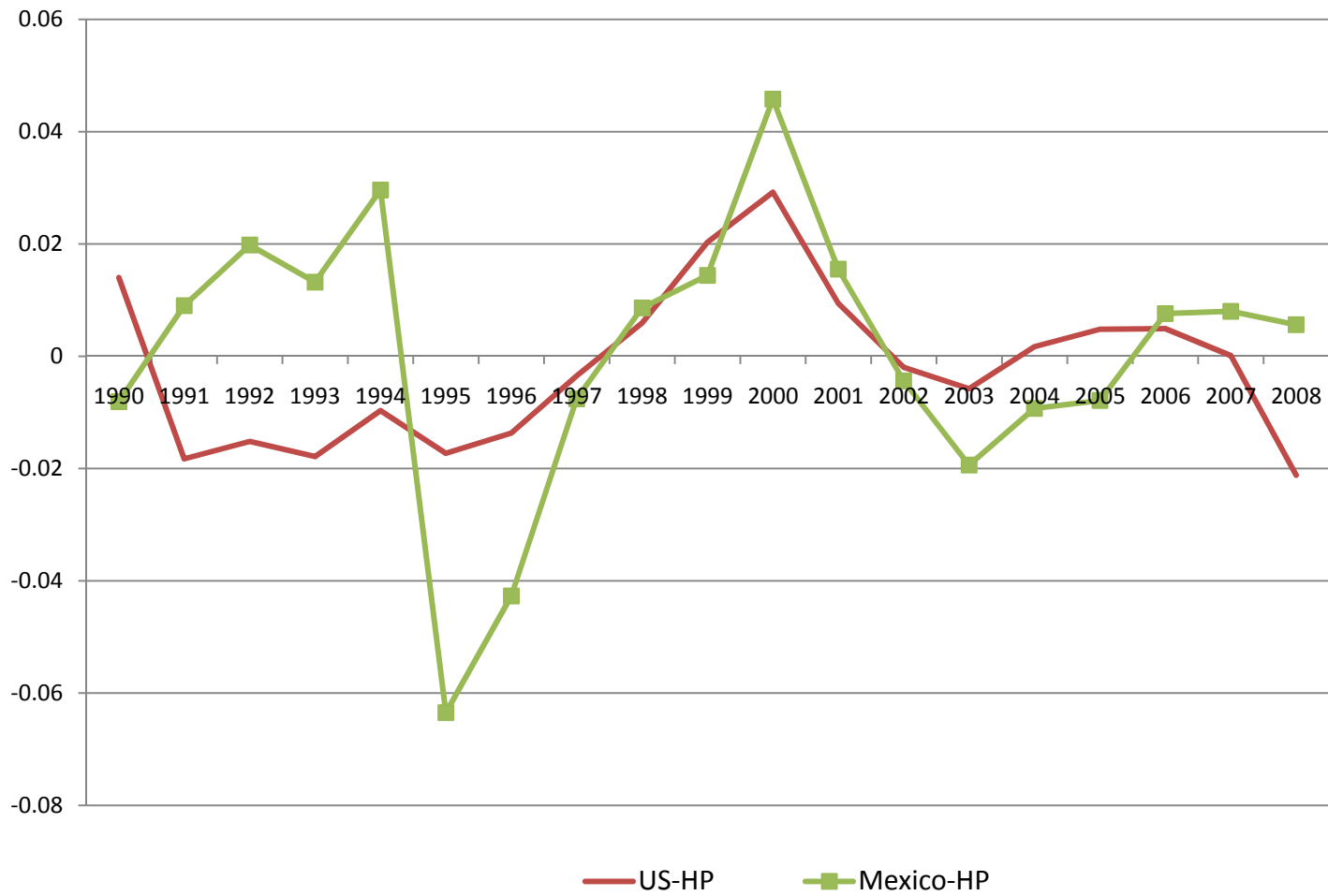
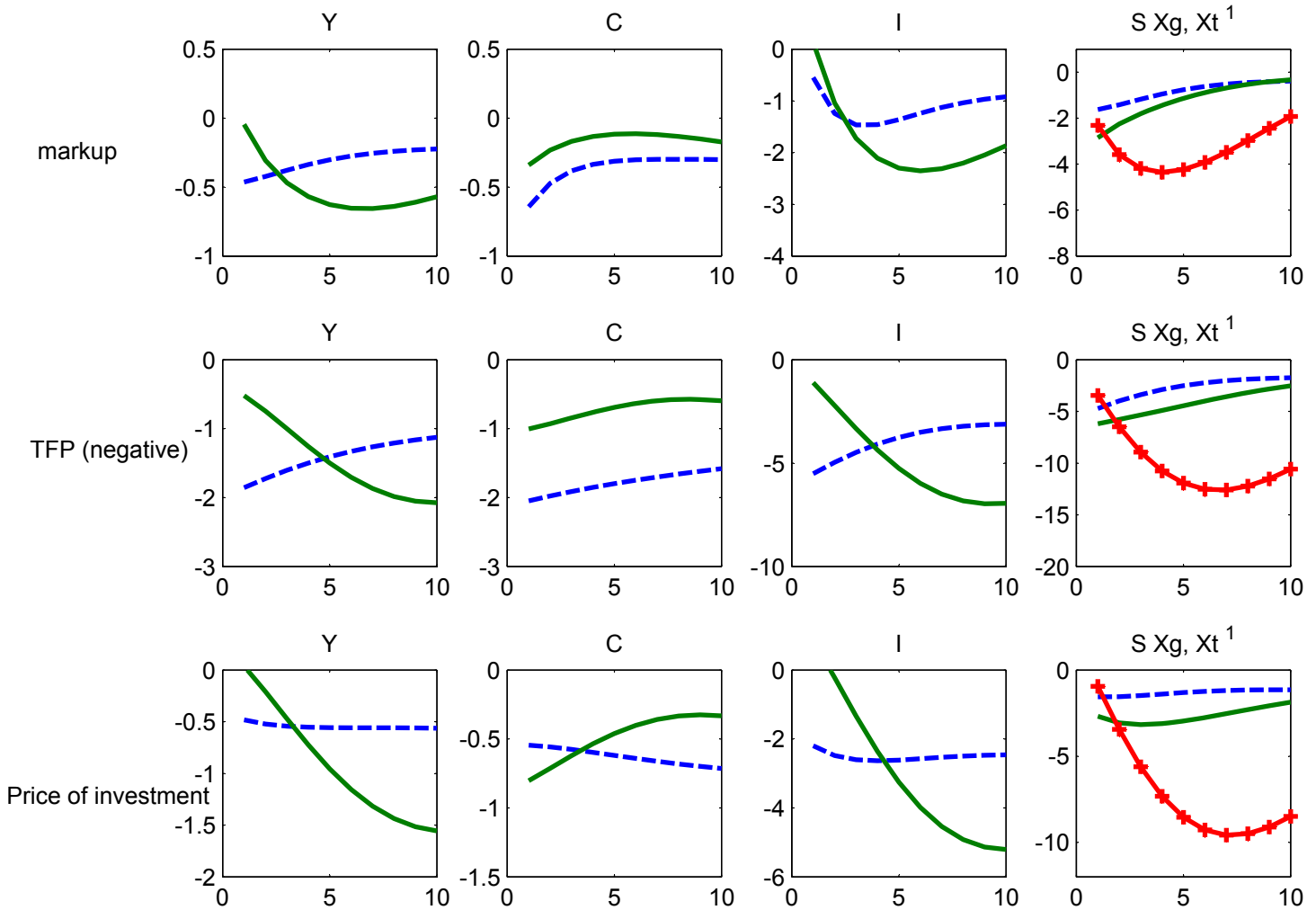# Figure 7A: HP-filtered GDP in Mexico and US

US-HP   Mexico-HP

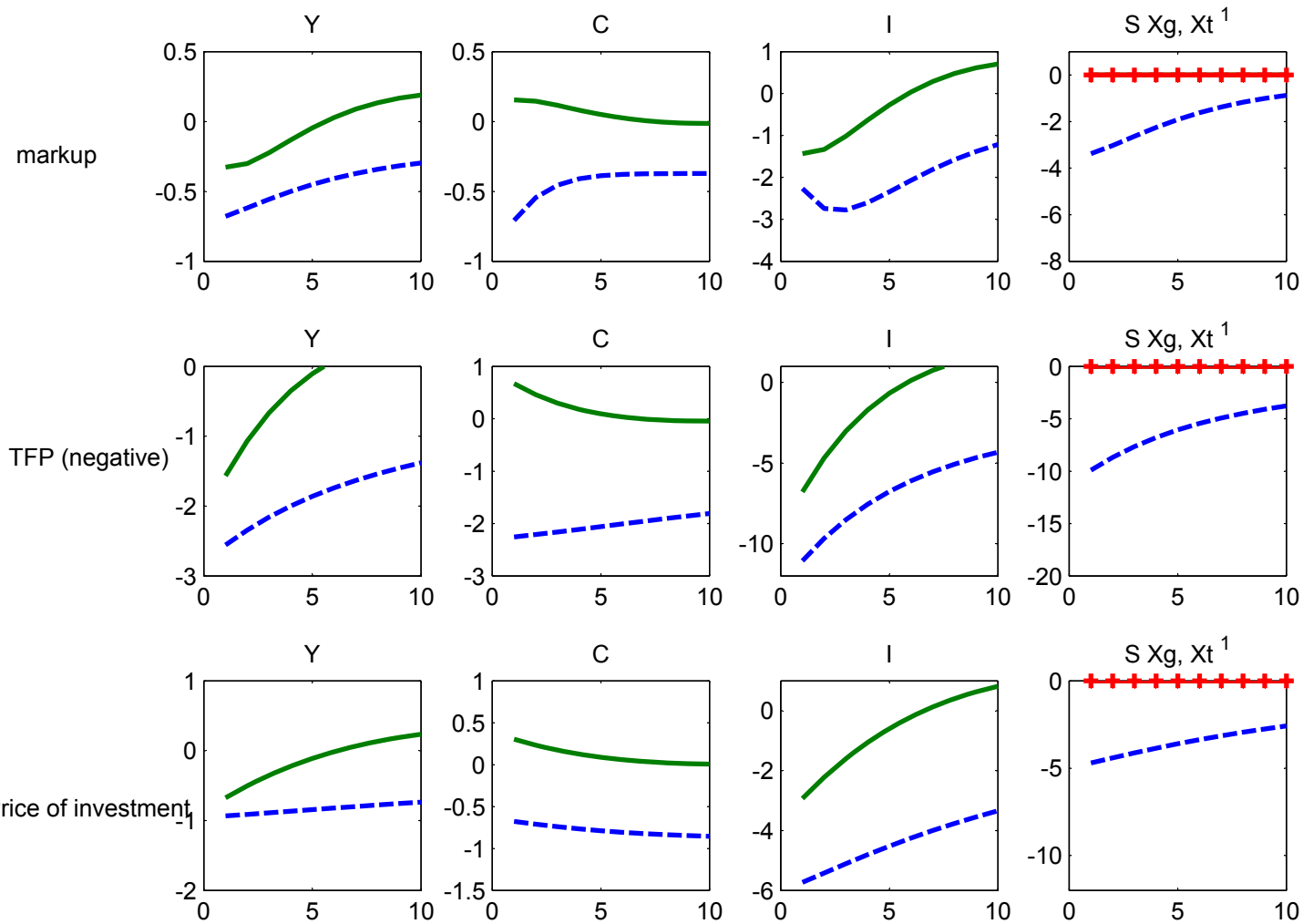Figure 7B: HP-filtered US output vs. Medium Term mexican output

Figure A1: IR to Shocks to Markup, TFP and Price of Investment in the U.S. in Model without AC

[1] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)

Figure A2: IR to Shocks to Markup, TFP and Price of Investment in the U.S. in Model without International Diffusion of Technology

[1] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)

Figure A3: Medium-run Response of Mexico's Variables to Detrended US GDP Innovations
(VAR estimated across period 1990-2007)
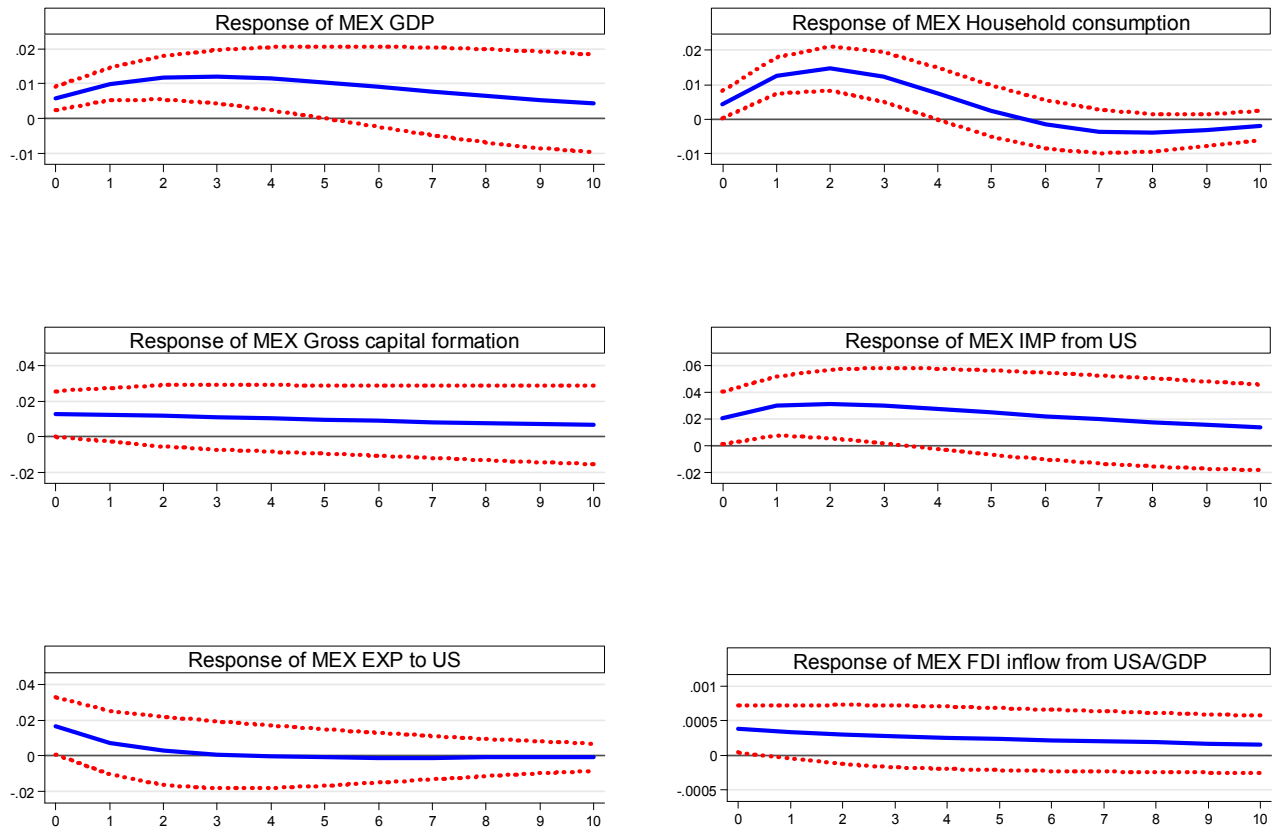
Note 1: Intervals of confidence at 90%.
Note 2: US GDP and other variables are filtered by Hodrick-Prescott and Band Pass Filter (frequency 8-50 years) respectively.
Note 3: All variables except FDI in VAR are in labor-force units.

Figure A4: Medium-run Response of Mexico's Variables to Detrended Mexico GDP Innovations
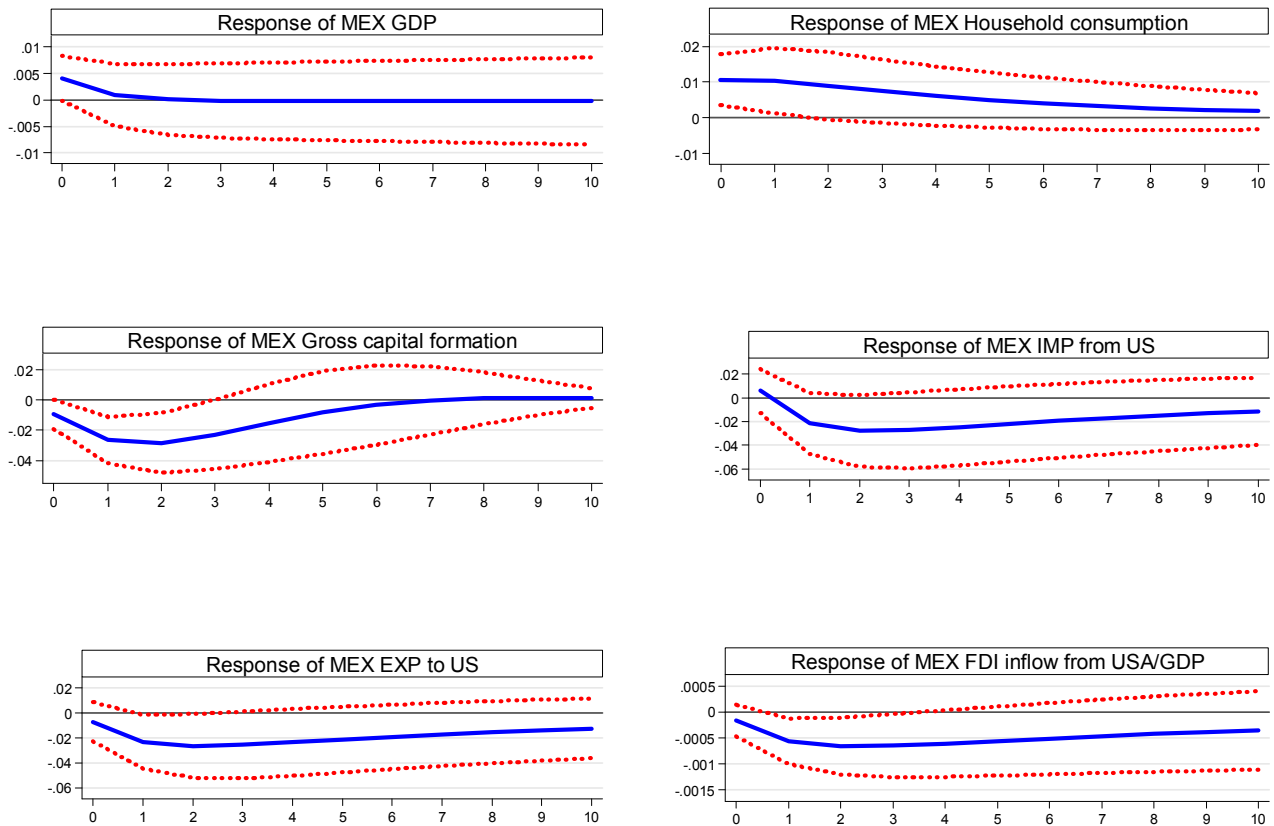(VAR estimated across period 1990-2007)

Note 1: Intervals of confidence at 90%.
Note 2: Mexico's GDP and other variables are filtered by Hodrick-Prescott and Band Pass Filter (frequency 8-50 years) respectively.
Note 3: All variables except FDI in VAR are in labor-force units.

Table 1 : Volatility Model vs. Data

MEXICO	High Frequency		Medium term Cycle	
	Data	Model	Data	Model
GDP	0.026	0.026 (0.015 , 0.041)	0.037	0.038 (0.018 , 0.068)
CONSUMPTION	0.031	0.03 (0.017, 0.044)	0.040	0.038 (0.021 , 0.059)
INVESTMENT	0.079	0.068 (0.032 , 0.124)	0.082	0.11 (0.041 , 0.22)
RELATIVE PRICE OF CAPITAL	0.029	0.021 (0.01 , 0.044)	0.042	0.033 (0.02 , 0.06)
IMPORTS (FROM US)	0.090	0.050 (0.025 , 0.09)	0.117	0.078 (0.032 , 0.15)
EXPORTS (TO US)	0.090	0.048 (0.02 , 0.088)	0.134	0.080 (0.027 , 0.17)
TRADE SUPLUS/GDP	0.014	0.023 (0.014 , 0.036)	0.026	0.033 (0.023, 0.057)
GROWTH IN INTERMEDIATE GOODS EXPORTED FROM US TO MEXICO	0.049 (all) 0.047 (dur.)	0.018 (0.013, 0.027)		
FDI/GDP	0.004	0.005 (0.002 , 0.013)	0.005	0.02 (0.007, 0.049)
US	**Data**	**Model**	**Data**	**Model**
GDP	0.013	0.015 (0.009 , 0.024)	0.015	0.020 (0.01 1, 0.035)
CONSUMPTION	0.008	0.020 (0.013 , 0.029)	0.012	0.025 (0.014 , 0.04)
INVESTMENT	0.064	0.044 (0.019 , 0.076)	0.084	0.061 (0.024 , 0.012)

Note: 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 2: Contemporaneous Correlation with Mexican and US Output

MEXICO	GDP USA		GDP MEXICO	
	Data	Model	Data	Model
GDP	0.43*	0.71	1.00	1.00
		(0.4, 0.9)		
CONSUMPTION	0.02	0.35	0.78***	0.76
		(-0.28, 0.78)		(0.39, 0.95)
INVESTMENT	0.6***	0.69	0.62***	0.77
		(0.47, 0.85)		(0.41, 0.94)
RELATIVE PRICE OF CAPITAL	0.13	-0.13	-0.54***	-0.45
		(-0.53, 0.26)		(-0.77 , 0.01)
IMPORTS (FROM US)	0.61***	0.81	0.83***	0.82
		(0.67, 0.9)		(0.52, 0.96)
EXPORTS (TO US)	0.68***	0.56	0.08	0.59
		(0.21, 0.81)		(0.03, 0.89)
MEXICAN TRADE SURPLUS/GDP	0.07	-0.74	-0.83***	-0.98
		(-0.92,-0.42)		(-0.99, -0.94)
GROWTH IN INTERMEDIATE GOODS EXPORTED FROM US TO MEXICO	0.2 (all) 0.28 (dur.)	0.42 (-0.07, 0.8)	0.35 (all) 0.42 (dur.)	0.42 (-0.03, 0.75)
FDI/GDP	0.23	0.89	0.11	0.83
		(0.71, 0.97)		(0.59, 0.95)

Note: Period 1990-2006. All variables but FDI are scaled by working age population in Mexico. All variables 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 investmentd eflator over the GDP deflator. Growth in intermediate goods is not filtered. 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 3: Cross-Correlogram Across Frequencies

	Lags of High Frequency US Output			
	0	1	2	3
MEDIUM TERM COMPONENT MEX GDP				
Data	0.28	0.49*	0.53**	0.39
Model	0.38**	0.45**	0.38**	0.21
MEDIUM TERM COMPONENT RELATIVE PRICE OF CAPITAL IN MEX				
Data	0.35	0.02	-0.24	-0.5**
Model	-0.15	-0.34*	-0.42*	-0.38

	Lags of High Frequency MEX Output			
	0	1	2	3
MEDIUM TERM COMPONENT MEX GDP				
Data	0.45**	0.32	0.05	-0.16
Model	0.6**	0.52**	0.29	-0.01
MEDIUM TERM COMPONENT RELATIVE PRICE OF CAPITAL IN MEX				
Data	-0.13	-0.32	-0.34	-0.22
Model	-0.4**	-0.52**	-0.48*	-0.32

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 with 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 4: Decomposition of output volatility

	High Frequency		Medium Term Cycle	
	US volatility	**Mexican volatility**	**US volatility**	**Mexican volatility**
US Shocks	0.97	0.64	0.98	0.66
Mexico Shocks	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.