# Medium Term Business Cycles in Developing Countries

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*Business cycle fluctuations in developed economies (N) tend to have large and persistent effects on developing countries (S). We study the transmission of business cycle fluctuations for developed to developing economies with a two-country asymmetric DSGE model with two features: (i) endogenous development of new technologies in N, and (ii) sunk costs of exporting and transferring the production of the intermediate goods to S. Consistent with the model we observe that the flow of technologies from N to S co-moves positively with output in both N and S. After calibrating the model to Mexico and the U.S., it can explain the following stylized facts: (i) shocks to N have a large effect on S; (ii) business cycles in N lead over medium term fluctuations in S; (iii) the outputs in S and N co-move more than their consumption; and (iv) interest rates in S are counter-cyclical .*

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*JEL Classification: E3, O3.*

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

The international transmission of business cycles is an important issue in international macroeconomics.[1] This paper explores the transmission of business cycle fluctuations from developed to developing economies. In particular, we present

[1]See, e.g., Backus, Findland and Kehoe (1992), Glick and Rogoff (1995), Gregory and Head (1999), Kehoe and Perri (2002), and Boileau, Normandin and Fosso (2010).

new evidence about the nature of this transmission and develop a model that can quantitatively account for the patterns that we identify in the data.

Business cycle fluctuations in developed economies ($N$) tend to have strong and persistent effects on developing countries ($S$). In particular, they affect output in developing countries not only at business cycle frequencies but also over the medium term. To understand the drivers of such a protracted transmission, we follow Broda and Weinstein (2006) and construct measures of technology diffusion based on the number of different (durable-manufacturing) SIC categories in which $N$ exports to $S$. We observe that the number of technologies exported from $N$ to $S$ co-moves positively with $N's$ cycle, both at high frequency and at lower frequencies. Furthermore, at low frequencies, the range of technologies imported from $N$ leads $S's$ productivity measures.

Our model is an asymmetric two-country model that has two key ingredients relative to a standard growth model. First, productivity growth in $N$ is endogenous and results from the creation of new intermediate goods through research and development (R&D). Second, firms in $N$ face a sunk cost of exporting intermediate goods to $S$ and transferring the production of the intermediate goods to $S$. The presence of sunk costs to exporting produces a lag in the adoption of new technologies in $S$ (see, e.g., Comin and Hobijn, 2010) that varies endogenously with the business cycles of developed and developing countries (see, e.g., Comin and Gertler, 2006). We interpret the transferring of production to $S$ as foreign direct investment (FDI). This allows us to capture realistically the nature of capital flows to developing countries, of which, since 1990, 70% have been in the form of FDI (e.g., Loayza and Serven, 2006).[2]

We calibrate the model to match some (steady state) moments of the U.S. ($N$) and Mexico ($S$) economies. Then, we simulate the economy by feeding TFP shocks to the U.S. and the Mexican economy and explore the transmission properties of the model. Our simulations show that the model does a reasonably good job in characterizing the key features of the short and medium term fluctuations in Mexico. First, unlike many RBC models (see, e.g., Backus, Kehoe and Kydland, 1992) our model generates a higher cross-country correlation of output than that of consumption. It does so because what drives the short term cross-country co-movement in output is the pro-cyclical response of Mexico's investment to U.S. shocks. Mexico's consumption, on the other hand, does not respond much to contemporaneous U.S. shocks. Second, our model also generates a large initial response of Mexico GDP to U.S. shocks, which helps explain why business cycle fluctuations are larger in developing than in developed economies. Third, consistent with the data, short term fluctuations in the U.S. produce cycles in Mexico at frequencies lower than those of the conventional business cycle. This occurs because shocks in the U.S. trigger a persistent change in the flow of new technologies to Mexico, leading to protracted changes in Mexico's productivity

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

level.

Fourth, the model generates counter-cyclical interest rates in Mexico endogenously in response to domestic shocks. As shown by Neumeyer and Perri (2005), an important feature of business cycles in developing countries is the counter-cyclicality of real interest rates. Based on this evidence, numerous authors have used shocks to interest rates in developing countries as a source of business cycles. In our model, the procyclical diffusion of technologies generates counter-cyclical fluctuations in the relative price of capital. These result in counter-cyclical capital gains that dominate the pro-cyclical response of the marginal product of capital (i.e. the dividend), thus inducing interest rates in $S$ (as well as the interest differential with respect to $N$) to be counter-cyclical.

Our framework is related to the product-cycle literature (see, e.g., Vernon, 1966, and Stokey, 1991). By embedding a product-cycle model in a business cycle framework, our model provides a unified account of the dynamics of productivity over high and low frequencies in $N$ and $S$. In particular, we show that adoption lags vary endogenously with business cycles and that the cyclical variation of technology generates hump-shaped responses of investment and output in $S$ to shocks in $N$.

The endogenous international diffusion of technologies emphasized in our framework is a different phenomenon from production sharing (see. e.g., Bergin et al. 2009; Zlate, 2010). Production sharing models generate fluctuations in output in $S$ in response to a shock in $N$ by assuming strong cyclicality of wages.[3] Firms in $N$ compare wages domestically and abroad and expand and contract their offshoring arrangements by increasing the extent of traded intermediaries. An implication of these models is that the flow of intermediate exports from $N$ to $S$ should be pro-cyclical with respect to $N's$ cycle but counter-cyclical with respect to $S$. In contrast, in our framework both recessions in $N$ and $S$ reduce the present discounted value of future profits from exporting a new intermediate good to $S$. As a result, the flow of new technologies from $N$ to $S$ is pro-cyclical with respect to both countries, and in particular to $S$. The data examined here shows strong evidence of the pro-cyclicality of the flow of new technologies with respect to $S$.[4] A related issue is that it is unlikely that production-sharing models or models of entry and trade in varieties (see, e.g., Ghironi and Melitz, 2005) can account for the low-frequency effects of $N's$ business cycle on $S's$ productivity and output that we observe in the data.[5] The key conceptual difference with these models is that,

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[3]Another important assumption of production sharing models, though more plausible, is that the share of manufacturing is larger in $S$ than in $N$.

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

[5]As we show in section 5, a key difference with trade in variety models is that the costs of affecting the extensive margin are fixed but not sunk. Modeling the transfer of technology as a sunk investment introduces a new state variable that changes the propagation and amplification of the shocks very significantly.

in ours, investment decisions in international technology transfer involve sunk costs, while in the literature they involve fixed costs. As a result, our mechanisms introduce new state variables that can generate the low-frequency international propagation that characterizes the data.

The rest of the paper is organized as follows. The next section presents some basic stylized facts. Section 3 develops the model. Section 4 evaluates the model through some simulations and provides intuition about the role of the different mechanisms. Section 5 discusses the results and compares them to the literature, and section 6 concludes.

## I. The cyclicality of international technology diffusion

In this section, we explore the role of technology diffusion in the propagation of business cycles from developed ($N$) to developing ($S$) countries. We focus on the two largest developed economies as $N$-countries: the U.S. and Japan.[6] We then select the $S$-countries based on the concentration of their (durable goods) imports from $N$.[7] That is, for each developing country without missing data and with a population of more than 2 million people, we construct an index of concentration of imports from each of the two $N$-countries. The index is just equal to the durable manufacturing imports from $N$ over total imports of durable manufacturing. For each country $N$, we select the 10 developing countries with the highest concentration.[8]

We collect data on three variables. First GDP per working age person as a measure of output both in $N$ and $S$. Next, following Greenwood and Yorukoglu (1997) and Greenwood, Hercowitz and Krusell (1997), we measure the level of embodied productivity by ratio of the GDP deflator over the investment deflator. Finally, following Broda and Weinstein (2006), we measure the range of technologies that diffuse internationally from $N$ to $S$ by the number of 6-digit SIC codes within durable manufacturing that have exports from $N$ to $S$ that are worth at least $1 million.

Our data are annual and cover the period 1960-2008. We use the full sample period to obtain the filtered series. However, as we explain below, we focus our analysis on the period 1990-2008. Because we want to allow for the possibility that shocks to $N$ have a very persistent effect in $S$, we analyze fluctuations at medium term frequencies in addition to conventional business cycles. Following Comin and Gertler (2006), we define the medium term cycle as fluctuations with periods

[6]We do not include the EU because it has a lower synchronization of the business cycles between its members than U.S. states or Japanese prefectures.

[7]The emphasis on durable manufacturing goods is driven by the model and because durable manufacturing goods surely embody more productive technologies than the average non-durable good. Having said that, the list of developing countries would be very similar if we ranked countries by concentration in imports or trade.

[8]The developing countries linked to the U.S. are Mexico, Dominican Republic, Costa Rica, Paraguay, Honduras, Guatemala, Venezuela, Peru, El Salvador and Nicaragua. The countries linked to Japan are Panama, Thailand, South Korea, Philippines, Vietnam, China, Pakistan, Indonesia, South Africa and Malaysia.

smaller than 50 years. The medium term cycle can be decomposed into a high frequency component and a medium term component. The high frequency component captures fluctuations with periods smaller than 8 years while the medium term component captures fluctuations with periods between 8 and 50 years. We use a Hodrick-Prescott filter to isolate fluctuations at the high frequency.[9] We isolate the medium term component and the medium term cycle using a band pass filter.

Two points are worth keeping in mind. First, it is important to be careful about the mapping between the frequency domain and the time domain. In principle, our measure of the cycle includes frequencies up to 50 years. However, Comin and Gertler (2006) have shown that its representation in the time domain leads to cycles on the order of a decade, reflecting the distribution of the mass of the filtered data over the frequency domain. For example, in the U.S. postwar period there are ten peaks and troughs in the medium term component of the cycle.[10] Second, despite their frequency, medium term cycles identified with macro series of conventional length are statistically significant (Comin and Gertler, 2006). We investigate the significance of the medium term component of per capita income in the countries in our sample by constructing confidence intervals using a bootstrap procedure.[11] We find that 52% of annual observations of the filtered series are statistically significant at 95% level. By way of comparison, we find that 80% of the HP-filtered annual observations are significant. Therefore, we consider that inferences based on series filtered to isolate medium term fluctuations are statistically informative.

After filtering the macro variables, we study their co-movement patterns during the period 1990-2008. We focus on this period for two reasons. First, the volume of trade and FDI inflows to developing countries increased very significantly during this period, making the mechanisms emphasized by our model more relevant than before. Second, after 1990, FDI became the most significant source of capital inflows from developed to developing economies, making our model's assumptions about the nature of international capital flows most appropriate for this period (Loayza and Serven, 2006). To show how much the international co-movement changed, we also present some results for the period 1975-90.

Before analyzing the data, an example can be useful to illustrate the co-movement patterns between developed and developing countries. Figure 1A plots the series of HP-filtered GDP in the U.S. and Mexico. The contemporaneous cross-country correlation is 0.42 (with a p-value of 7%). U.S. business fluctuations such as the internet-driven expansion during the second half of the 1990s, the burst of the

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[9]The HP-filtered series are very similar to the series that result from using a Band-Pass filter that keeps fluctuations with periodicity smaller than eight years (Comin and Gertler, 2006). We use the HP filter to isolate high-frequency fluctuations to make our findings more comparable to the literature.

[10]There are 22 peaks and troughs at conventional frequencies.

[11]Specifically, we use the bootstrap method described in Comin and Gertler (2006). Essentially, the method consists in padding the time series at both ends, and filtering the extended series. Then, for each period in the original series, we build a 95% confidence interval.

dot-com bubble in 2001, the 2002-2007 expansion and the 2008 financial crisis are accompanied by similar fluctuations in Mexico. Arguably, none of the shocks that caused these U.S. fluctuations originated in Mexico. Therefore, it is natural to think that the co-movement between Mexico and U.S. GDP resulted from the international transmission of U.S. business cycles.[12]

INSERT FIGURE 1A/1B HERE

The effects of U.S. business cycles on Mexico's GDP are very persistent and go beyond conventional business cycle frequencies. Figure 1B plots the medium term component of Mexico's GDP together with HP-filtered U.S. GDP. The lead-lag relationship between these variables can be most notably seen during the post 1995 expansion, the 2001 recession and the post-2001 expansion. Despite the severity of the effect of the Tequila crisis on the medium term component of Mexico's GDP, the latter strongly recovered with the U.S. post-1995 expansion. The Mexican medium term recovery lagged the U.S. boom by about two years. The end of Mexico's expansion also lagged the end of the U.S. expansion by one year. Finally, the post-2001 U.S. expansion also coincided with a boom in the medium term component of Mexico's GDP which continued to expand as late as 2008.

The top panel of Table 1A explores more generally these co-movement patterns using our panel of countries for the period 1990-2008. The first row reports the coefficient $\beta$ from the following regression:

$$HPy_{Sct} = \alpha + \beta * HPy_{Nct-k} + \epsilon_{ct}$$

where $HPy_{Sct}$ is HP-filtered output in developing country $c$, and $HPy_{Nct-k}$ is HP-filtered output in the developed economy associated with $c$ lagged $k$ years. We find that an increase by 1% in $N's$ output is associated with an increase by 0.42% in $S'$ output. This effect declines monotonically and becomes insignificant when $k = 2$.

The second row of Table 1A reports the coefficient $\beta$ from the following regression:

$$MTCy_{Sct} = \alpha + \beta * HPy_{Nct-k} + \epsilon_{ct}$$

where $MTCy_{Sct}$ is the medium term component of the medium term cycle of output in developing country $c$. High frequency fluctuations in output in $N$ are associated with even larger fluctuations in the medium term component of output in $S$. A 1% higher level of HP-output in $N$ is associated with a 0.63% higher medium term component of output in $S$. This association increases when we lag the impulse in $N$ by one year and remains the same when we lag it by two years. Note that, if the medium term cycle in $S$ was just an average of the

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[12]The only important Mexican shock over this period was the 1995 recession which, despite its virulence, was relatively short-lived.

short term fluctuations, we would tend to find smaller $\beta's$ in the second row than in the first one.[13]  Hence, the top panel of Table 1A suggests that short term fluctuations in $N$ affect mechanisms that induce fluctuations in $S$ at frequencies below the conventional business cycle.

To obtain a better understanding of what kind of mechanisms can generate such persistent international co-movement, we perform the same exercise but for the period 1975-1990. As argued above, the size of trade flows and foreign direct investment flows from developed to developing countries during this period were significantly smaller. The bottom panel of Table 1A shows that, during the 70s and 80s, there was no co-movement between output fluctuations in developed and developing countries at business cycle frequencies. Furthermore, we find no significant positive correlation between business cycle fluctuations in developed economies and the medium term component of output in developing ones. This evidence suggests that the mechanisms that drive the international co-movement were more important since around 1990. But, what can these mechanisms be?

INSERT TABLE 1A/1B/1C HERE

Table 1B shows that business cycle fluctuations in $N$ are positively associated with fluctuations in the number of durable manufacturing goods exported from $N$ to $S$. Since many new technologies are embodied in new durable manufacturing goods, this correlation suggests that the speed of diffusion of new technologies from $N$ to $S$ co-moves with $N$'s cycle. Table 1B also shows a strong co-movement between the flow of these technologies and the cycle in $S$.

Table 1C then explores the potential impact of fluctuations in the range of technologies imported on $S$' output and productivity over the medium term. Specifically, it shows that when looking at the medium term component of the medium term cycle, the range of durable manufacturing goods exported from $N$ to $S$ is significantly correlated with output in $S$. One reason for this finding is that, at relatively low frequencies, the range of capital goods imported from $N$ is a key driver of productivity in $S$. The second row of Table 1C presents further evidence on this hypothesis.  An increase in the range of durable manufacturing goods imported from $N$ leads to a lower price of investment goods in $S$. This association becomes more negative as we increase the lag in the range of intermediate goods. This may reflect the fact that newly adopted technologies by $S$ do not diffuse immediately among producers in $S$.[14]

The picture that emerges from this simple exploration of the data is that the persistent effect of business cycles in developed economies on their developing

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[13]Furthermore, given the typical persistence of business cycles fluctuations, the associations with lags would most likely be statistically insignificant.

[14]It is important to remark that, even if statistical agencies do not do a good job in adjusting their price deflators for gains from variety, one would expect the relative price of investment to reflect the gains from variety if the imported intermediate goods are used to produce new investment. This will occur not because statisticians recognize the productivity enhancing benefits from the goods at the border but because (capital goods) producers that use the new technologies will experience lower production costs that should be reflected in lower capital goods prices.

partners may be mediated by the pro-cyclical fluctuation in the speed of international technology diffusion, which affects the productivity in developing economies over the medium term. Next, we explore the effects of endogenizing the international diffusion of technologies in a real business cycle model.

## II.    Model

To investigate the drivers of international co-movement, we develop a two-country model of medium term business fluctuations. We denote the countries by North, $N$, and South, $S$. Our model is a conventional real business cycle model modified to allow for endogenous productivity and relative price of capital as in Comin and Gertler (2006). The model embeds a product lifecycle (e.g. Vernon, 1966; Wells, 1972; and Stokey, 1991). Technologies are embodied in intermediate goods which are developed in $N$ as a result of R&D activities. Initially, intermediate goods are only locally sold in $N$. Eventually, they can be exported to $S$ and finally their production can be transferred to $S$ (FDI) from where they are exported to $N$. The model nests a version where the international diffusion of technologies is exogenous. We study the effects of technology diffusion for the international transmission of business cycle fluctuations by comparing our model with the version with exogenous technology diffusion.

### A.    Households

In each country, there is a representative household that consumes, supplies labor and saves. It may save by either accumulating capital or lending to innovators. The household also holds equity claims in all monopolistically competitive firms in the country. It makes one period loans to innovators and rents capital to firms. Physical capital does not flow across countries. There is no international lending and borrowing and the only international capital flow is $N's$ FDI in $S$.

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

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

subject to the budget constraint

$$(2) \qquad C_{ct} = \omega_{ct} L_{ct} + \Pi_{ct} + D_{ct} K_{ct} - P_{ct}^k J_{ct} + R_{ct} B_{ct} - B_{ct+1}$$

where $\Pi_{ct}$ reflects corporate profits paid out fully as dividends to households, $D_{ct}$ denotes the rental rate of capital, $J_{ct}$ is investment in new capital, $P_{ct}^k$ is the price of investment, and $B_{ct}$ is the total loans the household makes at $t-1$ that are payable at $t$. $R_{ct}$ is the (possibly state-contingent) payoff on the loans.

The household's stock of capital evolves as follows:

$$(3) \qquad K_{ct+1} = (1 - \delta(U_{ct}))K_{ct} + J_{ct},$$

where $\delta(U_{ct})$ is the depreciation rate which is increasing and convex in the utilization rate as in Greenwood, Hercowitz and Huffman (1988).

The household's decision problem is simply to choose consumption, labor supply, capital and bonds to maximize equation (1) subject to (2) and (3).

### B.  Technology

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

$$(4) \qquad A_{Nt} = A_t^l + A_t^g + A_t^T, \text{ and}$$
$$(5) \qquad A_{St} = A_t^g + A_t^T.$$

Innovators in $N$ engage in R&D by investing final output to develop new intermediate goods. The stock of invented intermediate goods, $A_{Nt}$, evolves according to following law of motion:

$$(6) \qquad A_{Nt+1} - A_{Nt} = \phi \varphi_t A_{Nt} S_t - (1 - \phi)A_{Nt},$$

where $S_t$ are the expenditures in R&D, $(1 - \phi)$ is the per-period probability that an intermediate good becomes obsolete, and $\varphi_t$ represents the productivity of the R&D technology, which is taken as given by the innovator and takes the following form:

$$(7) \qquad \varphi_t = \chi S_t^{\rho-1}(\Omega_t)^{-\rho}, \text{ with } \rho \in (0, 1).$$

This formulation presents aggregate diminishing returns to R&D. The term $\Omega_t$ is a deterministic trend that ensures the existence of a balance growth path in the economy.[15]

After developing a new technology, the innovator is granted a patent that protects her rights to the monopolistic rents from selling the intermediate good that

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[15]In particular, $\Omega_t = (1 + g_y)^t$ where $g_y$ is the constant growth rate of the economy in steady state.

embodies it. These rents have a market value of $v_t$. The producers of local intermediate goods have the option of engaging in a stochastic investment that, if successful, permits the diffusion of the intermediate good to $S$. The probability of succeeding in this investment is $\lambda_g(A_t^l x_t^g / \Omega_t)$, where $x_t^g$ is the amount of $N's$ aggregate output invested, and the function $\lambda_g(.)$ satisfies $\lambda_g' > 0$, $\lambda_g'' < 0$.[16],[17]

Global intermediate goods are exported from $N$ to $S$. Exporters face an iceberg transport cost so that $1/\psi$ (with $\psi < 1$) units of the good need to be shipped so that one unit arrives in its destination. The South has comparative advantage in assembling manufacturing goods (see, e.g., Iyer, 2005). In particular, it takes one unit of final output to produce a unit of intermediate good in $N$, while if the intermediate good is assembled in $S$, it only takes $1/\xi(< 1)$ units of country $S$ output. Producers of global intermediate goods may take advantage of this cost advantage by transferring the production of the global intermediate goods to $S$. As for exporting, we model the transfer of production as stochastic investment. The probability of succeeding in this investment is $\lambda_T(A_t^g x_t^T / \Omega_t)$, where the function $\lambda_T(.)$ satisfies $\lambda_T' > 0$, $\lambda_T'' < 0$, and $x_t^T$ is the amount of $S's$ aggregate output invested. We denote by $e_t$ the relative price of $N's$ output in terms of $S$ (i.e., the exchange rate). Because $x^T$ is $S's$ aggregate output invested by a foreign firm to start producing in $S$, we denote it as FDI.

Given this product cycle structure, the stock of global and transferred intermediate goods evolve according to the following laws of motion:

$$(8) \qquad A_{t+1}^g = \phi \lambda_g(A_t^l x_t^g / \Omega_t) A_t^l + \phi(1 - \lambda_T(A_t^g x_t^T / \Omega_t)) A_t^g$$

$$(9) \qquad A_{t+1}^T = \phi \lambda_T(A_t^g x_t^T / \Omega_t) A_t^g + \phi A_t^T.$$

### C.  Production

The production side of the economy is composed of two sectors that produce, respectively, aggregate output and investment. In both sectors, we allow for entry and exit that amplifies business cycle shocks in a way similar to price or wage rigidities. In addition it allows our model to capture the high-frequency counter-cyclicality of the relative price of investment which is an important feature of business cycles. The dynamics of intermediate goods described in the previous subsection determine the stock of intermediate goods available for production in each country. Intermediate goods are embodied in new investment goods and

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

[17]Note that this formulation includes an externality from the stock of intermediate goods. This is necessary to ensure balanced growth. For practical purposes, it is irrelevant whether the externality depends on the stock of local or global intermediate goods.

determine their efficiency over the medium and long term. For simplicity, disembodied technological change is taken as exogenous.[18]

Aggregate output is produced competitively by combining the outputs produced by $N_{ct}^y$ differentiated producers as follows:

$$(10) \qquad Y_{ct} = \left[ \int_0^{N_{ct}^y} Y_{jct}^{1/\mu} dj \right]^{\mu}$$

Each differentiated producer has access to the following production function:

$$(11) \qquad Y_{jct} = \chi_{ct} \left( U_{cjt} K_{cjt} \right)^{\alpha} \left( L_{cjt} \right)^{1-\alpha},$$

where $U_{cjt}$, $K_{cjt}$ and $L_{cjt}$ are, respectively, the capital utilization rate, capital rented and labor hours hired by firm $j$ in country $c$. $\chi_{ct}$ is an exogenous trend-stationary TFP shock that evolves as follows:

$$(12) \qquad \log(\chi_{ct}) = (1 - \rho_\chi)g + \rho_\chi \log(\chi_{ct-1}) + \epsilon_{ct}^\chi,$$

where $g$ is the exogenous growth rate of TFP in the balanced growth path.

Investment is produced competitively by combining $N_{ct}^k$ differentiated final capital goods as follows:

$$J_{ct} = \left[ \int_0^{N_{ct}^k} I_{rct}^{1/\mu_k} dr \right]^{\mu_k}.$$

Each final capital good is produced by combining the $A_{ct}^k$ intermediate goods available in the economy $c$:

$$I_{rct} = \left[ \int_0^{A_{ct}^k} \left( I_{ct}^r(s) \right)^{1/\theta} ds \right]^{\theta}, \ \theta > 1$$

Final firms incur every period in a fixed (entry) cost $o_{ct}^s$ to remain productive. In particular,

$$o_{ct}^s = o_c^s \Omega_t \text{ for } s = \{k, y\},$$

where the $\Omega_t$ is a deterministic term that grows at the same rate as the economy in the balanced growth path and ensures its existence.[19]

The number of final firms is determined by a free entry condition that equalizes the entry cost with the profits in the period. Note that this formulation introduces a significant difference between entry/exit and development/diffusion

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[18]Comin and Gertler (2006) endogenize both embodied and disembodied technological change in a one country setting.

[19]In particular, $\Omega_t = (1 + g_y)^t = (1 + g)^{t/(1-\alpha)} * (1 + g_A)^{t(\theta-1)\alpha}$, where $g_A$ is the growth rate of the number of intermediate goods along the balanced growth path.

of technologies. The former involve fixed costs while the latter involve sunk costs. As a result, the number of intermediate goods available for production are state variables while the number of final goods firms are not. In section 5 we study the importance of this assumption by changing the nature of the investments required for intermediate goods to diffuse from sunk to fixed costs.

### III.   Symmetric equilibrium

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

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

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(13) \quad Y_{Nt} = C_{Nt} + S_t + x_t^g A_t^l + \overbrace{\frac{\mu-1}{\mu} Y_{Nt} + \frac{\mu^K-1}{\mu^K} P_{Nt}^K J_{Nt}}^{\text{overhead costs}}
$$

$$
+ \underbrace{\frac{P_{Nt}^K J_{Nt}}{\mu^K \theta a_{Nt}} \left(1 + \frac{A_t^g}{A_t^l}\right)}_{\text{intermediates sold to N}} + \underbrace{e_t \frac{P_{St}^K J_{St}}{\mu^K \theta a_{St}} \frac{A_t^g}{A_t^T} \left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}}}_{\text{intermediates sold to S}}
$$

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

$$
(14) \quad Y_{St} = C_{St} + x_{St}^T A_t^g + \overbrace{\frac{\mu-1}{\mu} Y_{St} + \frac{\mu^K-1}{\mu^K} P_{St}^K J_{St}}^{\text{overhead costs}}
$$

$$
+ \underbrace{\frac{P_{Nt}^K J_{Nt}}{e_t \mu^K \theta a_{Nt}} \frac{A_t^T}{A_t^l} \left(\frac{\psi \xi}{e_t}\right)^{\frac{1}{\theta-1}}}_{\text{intermediates sold to N}} + \underbrace{\frac{P_{St}^K J_{St}}{\mu^K \theta a_{St}} \xi^{\frac{1}{\theta-1}}}_{\text{intermediates sold to S}} .
$$

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

The output produced in each country is given by

$$
(15) \quad Y_{ct} = (1+g)^t (N_{ct}^y)^{\mu-1} (U_{ct} K_{ct})^\alpha (L_{ct})^{1-\alpha},
$$

where the term $(N_{ct}^y)^{\mu-1}$ reflects the efficiency gains from the variety of final output producers.

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

$$(16) \qquad (1-\alpha)\frac{Y_{ct}}{L_{ct}} = \mu\mu_{ct}^w L_{ct}^\zeta C_{ct}.$$

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

$$(17) \qquad \alpha\frac{Y_{ct}}{K_{ct}} = \mu\left[D_{ct} + \delta(U_{ct})P_{ct}^K\right]$$

$$(18) \qquad \alpha\frac{Y_{ct}}{U_{ct}} = \mu\delta'(U_{ct})P_{ct}^K K_{ct}.$$

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

$$(19) \qquad K_{ct+1} = (1 - \delta(U_{ct}))K_{ct} + J_{ct}$$

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

$$(20) \qquad E_t\left\{\Lambda_{c,t+1}\frac{\left[\alpha\frac{Y_{ct}}{\mu K_{ct+1}} + (1 - \delta(U_{ct+1}))P_{ct+1}^K\right]}{P_{ct}^K}\right\} = 1,$$

where

$$(21) \qquad \Lambda_{c,t+1} = \beta C_{ct}/C_{ct+1}.$$

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

$$(22) \qquad E_t\left\{\Lambda_{c,t+1}R_{ct+1}\right\} = E_t\left\{\Lambda_{c,t+1}\frac{\left[\alpha\frac{Y_{ct}}{\mu K_{ct+1}} + (1 - \delta(U_{ct+1}))P_{ct+1}^K\right]}{P_{ct}^K}\right\}.$$

Note that, since capital markets in $N$ and $S$ are not integrated, interest rates may differ across countries.

*Free Entry.–* Free entry by final goods producers in each sector yields the follow-

ing relationship between operating profits and the number of final good producers:

$$(23) \qquad \frac{\mu - 1}{\mu} \frac{Y_{ct}}{N_{ct}} = o_{ct}^y;$$

$$(24) \qquad \frac{\mu^K - 1}{\mu^K} \frac{P_{ct}^K J_{ct}}{N_{ct}^K} = o_{ct}^K.$$

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

$$(25) \qquad \pi_t = \left(1 - \frac{1}{\theta}\right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l}$$

$$(26) \qquad \pi_t^g = \left(1 - \frac{1}{\theta}\right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} + \left(1 - \frac{1}{\theta}\right) e_t \frac{P_{St}^K J_{St}}{\mu_k a_{St} A_t^T} \left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}},$$

$$(27) \qquad \pi_t^T = \left(1 - \frac{1}{\theta}\right) \frac{P_{Nt}^K J_{Nt}}{\mu_k a_{Nt} A_t^l} \left(\frac{\psi \xi}{e_t}\right)^{\frac{1}{\theta-1}} + \left(1 - \frac{1}{\theta}\right) e_t \frac{P_{St}^K J_{St}}{\mu_k a_{St} A_t^T},$$

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

$$(28) \qquad a_{Nt} = \left[1 + \frac{A_t^g}{A_t^l} + \frac{A_t^T}{A_t^l} \left(\frac{\psi \xi}{e_t}\right)^{\frac{1}{\theta-1}}\right],$$

$$(29) \qquad a_{St} = \left[\frac{A_t^g}{A_t^T} \left(\frac{\psi e_t}{\xi}\right)^{\frac{1}{\theta-1}} + 1\right].$$

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

$$(30) \quad v_t = \pi_t - x_t^g + \phi E_t \left\{\Lambda_{N,t+1} \left[\lambda_g (A_t^l x_t^g / \Omega_t) v_{t+1}^g + \left(1 - \lambda_T (A_t^g x_t^T / \Omega_t)\right) v_{t+1}\right]\right\},$$

$$(31)$$
$$v_t^g = \pi_t^g - e_t x_t^T + \phi E_t \left\{\Lambda_{N,t+1} \left[\lambda_T (A_t^g x_t^T / \Omega_t) v_{t+1}^T + \left(1 - \lambda_T (A_t^g x_t^T / \Omega_t)\right) v_{t+1}^g\right]\right\},$$

$$(32) \qquad v_t^T = \pi_t^T + \phi E_t \left\{\Lambda_{N,t+1} v_{t+1}^T\right\},$$

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

$$(33) \qquad 1 \;=\; \phi\left(A_t^l/\Omega_t\right)\lambda_g'(A_t^l x_t^g/\Omega_t)E_t\left\{\Lambda_{N,t+1}\left(v_{t+1}^g - v_{t+1}\right)\right\},$$

$$(34) \qquad e_t \;=\; \phi\left(A_t^g/\Omega_t\right)\lambda_T'(A_t^g x_t^T/\Omega_t)E_t\left\{\Lambda_{N,t+1}\left(v_{t+1}^T - v_{t+1}^g\right)\right\}.$$

The optimal investment, $x^g$ and $x^T$, equalize, at the margin, the cost and expected benefit of exporting the intermediate good to $S$ and of transferring the production of the intermediate good to $S$.[20] The marginal cost of investing one unit of output in exporting the good is 1, while the expected marginal benefit is equal to the increase in the probability of international diffusion times the discounted gain from making the intermediate good global $\left(i.e.,\ v_{t+1}^g - v_{t+1}\right)$. Equation (31) illustrates why the international diffusion of technologies is pro-cyclical. The value of global intermediate goods is approximately equal to the value of local goods plus the value from exporting goods to $S$. Since demand in $S$ is pro-cyclical, the capital gain from exporting an intermediate good (i.e. $v_{t+1}^g - v_{t+1}$) is pro-cyclical. It follows then from (33) that, since $\lambda^g$ is a concave function, $x_t^g$ is pro-cyclical.

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

$$(35) \qquad S_t = \phi E_t\left\{\Lambda_{N,t+1}v_{t+1}(A_{t+1} - \phi A_t)\right\}.$$

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

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

(36)

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

*Evolution of state variables.–* The evolution of productivity over the medium and long term in $N$ and $S$ depends on the dynamics of innovation, international diffusion and capital accumulation. The stock of capital evolves according to equation (3). The dynamics for the stock of intermediate goods, global goods

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[20]Given the symmetry between these two FOCs, we discuss only the exporting decision.

and transferred goods are characterized, respectively, by equations (6), (8) and (9).

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

$$(37) \qquad P_{Nt}^K \;=\; \mu^K \theta N_{kNt}^{-(\mu_{kN}-1)}(a_{Nt} A_t^l)^{-(\theta-1)},$$

$$(38) \qquad P_{St}^K \;=\; \mu^K \theta \frac{(N_{kSt})^{-(\mu_{kS}-1)}}{\xi}(a_{St} A_t^T)^{-(\theta-1)}.$$

Observe from (37) and (38) that the efficiency gains associated with $A_{ct}$ and $N_{ct}^k$ reduce the marginal cost of producing investment. Fluctuations in these variables are responsible for the evolution in the short, medium and long run of the price of new capital, $P_{ct}^K$. However, $A_{ct}$ and $N_{ct}^k$ affect $P_{ct}^K$ at different frequencies.

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

*Exogenous technology diffusion* .– The version of the model with exogenous technology diffusion we study below is characterized by the same system of equations with the exception that $x^g$ and $x^T$ are fixed at their steady state levels. That is, at the levels in which equations (33) and (34) hold along the balanced growth path.

## IV.  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, especially, 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 log-linearizing 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.[21] We describe the calibration before turning to some numerical exercises.

### A.  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

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[21] Anderson and Moore (1983).

greatest extent possible, we use the restrictions of balanced growth to pin down parameter values. Otherwise, we look for evidence elsewhere in the literature. There are a total of twenty-three parameters summarized in Table 2. Eleven appear routinely in other studies. Six relate to the process of innovation and R&D and were used, among others, in Comin and Gertler (2006). Finally, there are six new parameters that relate to trade and the process of international diffusion of intermediate goods. 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 $S$.


INSERT TABLE 2 HERE


We calibrate the six parameters that govern the interactions between $N$ and $S$ by matching information on trade flows, and U.S. FDI in Mexico, the micro evidence on the cost of exporting and the relative productivity of U.S. and Mexico in manufacturing. First, we set $\xi$ to 2 to match Mexico's relative cost advantage over the U.S. in manufacturing identified by Iyer (2005). We set the inverse of the iceberg transport cost parameter, $\psi$, to 0.95,[22] the steady state probability of exporting an intermediate good, $\lambda^g$, to 0.0875, and the steady state probability of transferring the production of an intermediate good to $S$, $\lambda^T$, to 0.0055. This approximately matches the share of Mexican exports and imports to and from the U.S. in Mexico's GDP (i.e. 18% and 14%, respectively) and the share of intermediate goods produced in the U.S. that are exported to Mexico. Specifically, Bernard, Jensen, Redding and Schott (2007) estimate that approximately 20 percent of U.S. durable manufacturing plants export. However, these plants produce a much larger share of products than non-exporters. As a result, the share of intermediate goods exported should also be significantly larger. We target a value of 33% for the share of intermediate goods produced in the U.S. that are exported. This yields an average diffusion lag to Mexico of 11 years, which seems reasonable given the evidence (see, e.g. Comin and Hobijn, 2010).

Das, Roberts and Tybout (2007) have estimated that the sunk cost of exporting for Colombian manufacturing plants represents between 20 and 40 percent of their annual revenues from exporting. We set the elasticity of $\lambda^g$ with respect to investments in exporting, $\rho_g$, to 0.8 so that the sunk cost of exporting represents approximately 30 percent of the revenues from exporting. The elasticity of $\lambda^T$ with respect to FDI expenses, $\rho_T$, together with the steady state value of $\lambda^T$, determine the share of U.S. FDI in Mexico in steady state. We set $\rho_T$ to 0.5 so that U.S. FDI in Mexico represents approximately 2% of Mexican GDP.

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[22]Interestingly, the value of $\psi$ required to match the trade flows between the US and Mexico is smaller than the values used in the literature (e.g. 1/1.2 in Corsetti et al., 2008) because of the closeness of Mexico and the US and their lower (non-existent after 1994) trade barriers.

*B.   Impulse response functions*

In our model there are several variables that can be the sources of economic fluctuations. For concreteness, we present most of our results using TFP shocks (i.e. shocks to the level of disembodied productivity) both in the U.S. and Mexico as the source of fluctuations. However, as we show below, our findings are robust to alternative sources of fluctuations such as shocks to the price of investment and to the wedge markup. Throughout, we use solid lines for the responses in Mexico and dashed lines for the responses in the U.S.

*Exogenous international diffusion.* – We start by considering the version of our economy where the rate of international diffusion of technologies is fixed (Figure 2). That is, $\lambda^T$ and $\lambda^g$ are constant and equal to their steady state values (i.e., 0.0875 and 0.0055, respectively). The response of the U.S. economy to a domestic TFP shock is very similar to the single-country version presented in Comin and Gertler (2006). In particular, a negative TFP shock reduces the marginal product of labor and capital causing a drop in hours worked (panel 2) and in the utilization rate of capital. The drop in hours worked and in the utilization rate causes a recession (panel 1). The response of U.S. output to the shock is more persistent than the shock itself (panel 12) due to the endogenous propagation mechanisms of the model. In particular, the domestic recession reduces the firms' incentives to invest in physical capital and that leads to a drop in the demand for intermediate goods. As a result, the return to R&D investments also drops, leading 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 forty percent of its initial response.

<center>INSERT FIGURE 2 HERE</center>

The U.S. shock has important effects on Mexico's economy in the short term. When the U.S. experiences a recession, the demand for Mexican intermediate goods declines (i.e. intensive margin of trade). In addition, the lower current and future output reduces Mexican investment upon impact. The decline in aggregate demand is matched by an equivalent drop in Mexican aggregate supply caused by a reduction in the utilization rate of capital, hours worked and net entry (which leads to a reduction in the efficiency of final output production). However, unlike the estimates from Tables 1A-1C, the response of the Mexican economy to the U.S. shock is monotonic, less persistent, and always smaller than the response of the U.S. economy. This is also the case for the wage markup and price of investment shocks (see Figure A1 in the non-published Appendix).

*Correlated shocks.* – A brute-force way to increase the impact of U.S. shocks in Mexico is to impose an exogenous correlation in the shocks processes of the U.S. and Mexican economy. This fix raises the question of what could be driving the correlation of the shocks. In reality, few shocks are international in nature.

Therefore, the cross-country correlation between shocks should be relatively small. Indeed, if we focus on TFP shocks, the empirical contemporaneous cross-country correlation in TFP tends to be relatively small. For the case of Mexico and the US, the correlation between HP-filtered annual TFP since 1990 is 0.39.[23]

<div align="center">INSERT FIGURE 3 HERE</div>

Despite these caveats, it may still be instructive to explore how allowing for cross-country correlation in TFP shocks affects the response of the Mexican economy to a U.S. shock. Figure 3 plots the impulse response to a U.S. shock when calibrating the contemporaneous effect of U.S. TFP on Mexico TFP at 0.4, which we regard as an upper bound.[24] Despite the exogenous correlation of the shocks, we continue to find that both the impact of the U.S. shock and, especially, the persistence of its effects are larger in the U.S. than in Mexico. We therefore conclude that the model with exogenous technology diffusion does not capture the pattern of international co-movement we have documented in section 2.

*Endogenous international technology diffusion.* – Next, we explore the role of the endogenous diffusion of technologies in the international propagation of shocks. Figure 4 plots the response to a contractionary shock to U.S. TFP in the full-blown model. The response of the U.S. economy is very similar to Figure 2, where international diffusion was exogenous. This is the case because potential feedbacks from Mexico are negligible for the U.S. Also, as in Figure 2, the U.S. shock has an important effect on the Mexican economy upon impact. The magnitude of the initial response is similar because the initial propagation channel is the same (a drop in the demand for Mexican exports). However, the shape and persistence of the response changes significantly once we allow for the speed of international technology diffusion to vary endogenously. In particular, the response of the Mexican economy to a U.S. shock is hump-shaped; within two years, it surpasses the effect that the shock has on the U.S. itself, reaching the maximum impact approximately within five years. After ten years, the effect of the shock in Mexican output is still similar to the initial impact.

<div align="center">INSERT FIGURE 4 HERE</div>

Why such a protracted and non-monotonic impact of U.S. shocks in Mexico? By endogenizing the diffusion of technology from the U.S. to Mexico, we introduce new margins of pro-cyclical variation in the state variables that govern the medium term dynamics of productivity in Mexico, $A^g$ and $A^T$. More specifically, contractionary shocks such as a negative shock to U.S. TFP reduce the return to exporting new intermediate goods and to transferring their production to Mexico. As a result, fewer resources are devoted to these investments, $x^g$ and $x^T$, (panel

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[23]Since 1980 it is -0.02 and since 1950 it is 0.11.

[24]Kehoe and Perri (2002) set the cross-country correlation of TFP shocks in their two-country model to 0.25 which they claim is in line with the VAR estimates of U.S. and a subsample of Western European countries (Baxter and Crucini, (1995), Kollmann (1996) and Backus, Kehoe and Kydland (1992)).

7). Because the stock of Mexican technologies ($A^g$ and $A^T$) are state variables, declines in $x^g$ and $x^T$ only generate a gradual reduction of the stock of intermediate goods available for production in Mexico relative to the steady state (panel 8). Since the stock of intermediate goods determines the productivity in the capital producing sector, this results in a reduction in the productivity of capital which manifests itself in a higher relative price of investment (panel 6) over the medium term.

The prospect of lower aggregate demand, initially, reduces investment causing net exit of final investment good producers. Due to the presence of efficiency gains from the number of final capital producers, exit reduces the efficiency in the production of investment goods causing an initial increase in the price of investment (panel 6).[25] However, note that the initial drop of investment in Mexico is smaller than in the U.S. This is the case because, in Mexico, the price of investment is expected to increase more than in the U.S. Since investment is cheap relative to its future price, Mexican firms, initially, undertake smaller cuts in investment. As the price of investment gradually increases, Mexican investment drops further contributing to the subsequent drop in output. This is how the endogenous diffusion and international transfer of technologies generate a hump-shaped response for the number of intermediate goods, productivity, investment and output in Mexico.[26]

One may wonder about the nature and values of the parameters that affect the hump-shaped response of Mexican technology to the U.S. shock. Inspection of the laws of motion of $A^g$ and $A^T$ (equations 8 and 9) suggests that the elasticities of diffusion and technology transfer with respect to $x^g$ and $x^T$ are key in governing these dynamics. In particular, they play two roles. First, for given investments $x^g$ and $x^T$, the elasticities determine the contribution of the investments to the number of intermediate goods available for production (and produced) in Mexico. Second, from the optimal investment equations (33) and (34), the higher the elasticities, the larger are the fluctuations in $x^g$ and $x^T$ in response to a given expected capital gain. These intuitions are illustrated in Figure 5 where we plot the impulse response function to a U.S. TFP shock in a version of the model where we have calibrated the elasticities of $\lambda_g$ and $\lambda_T$ with respect to $x^g$ and $x^T$ to 0.2 (instead of our baseline values of 0.8 and 0.5, respectively). We consider that this calibration captures a key aspect of the pre-NAFTA/pre-globalization period where investments in FDI and in exporting new goods were much less prominent. As Figure 5 shows, in this scenario, U.S. shocks had a much more transitory effect on Mexican macro variables.[27]

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[25]The price of investment also increases upon impact due to the shift in the use from foreign to domestically-produced intermediate goods after the initial depreciation of the peso (to be discussed below).

[26]The effect that the international diffusion of technology has on the persistence of output in developing countries 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.

[27]In results not reported, we have shown that the initial impact of the U.S. shock in Mexico also is

INSERT FIGURE 5 HERE

Still, one may wonder why is it the case that medium term fluctuations in Mexican technology in response to a U.S. shock may be larger than in the U.S. itself. This is the result of various forces. First, the stock of technologies available for production is smaller in Mexico than in the U.S.; therefore, a given change in the flow of new technologies will tend to generate larger fluctuations over the medium term in the stock of available technologies. Second, anticipating the effects that a given fluctuation in $x^g$ and $x^T$ have on $A^g$ and $A^T$ (and therefore on output and investment), over the medium term, $x^g$ and $x^T$ tend to drop more than R&D, $S$, in response to a contractionary U.S. shock. The final element that contributes to generating a higher eventual impact of the U.S. shock in Mexico than in the U.S. itself is the exchange rate (panel 11, where an increase represents a real appreciation in Mexico vis-a-vis the U.S.). The depreciation of the peso in response to the shock has opposite effects in the effective stock of available intermediate goods in the U.S. and Mexico. In the U.S., a depreciation of the peso makes transferred intermediate goods more attractive increasing the effective number of intermediate goods available for production (i.e., $a_{Nt} * A_t^l$); in Mexico, instead, the depreciation of the peso makes more expensive imported intermediate goods reducing the efficiency gains from using global intermediate goods and hence the effective number of available intermediate goods (i.e., $a_{St} * A_t^g$).

We conclude our qualitative exploration of the model's response to a U.S. shock by studying the impact on the exchange rate. In steady state, there is a net inflow of FDI to Mexico in the form of the investments made by multinationals that want to transfer the production of intermediate goods to Mexico. The surplus in the financial account implies that in steady state, Mexico has a deficit in the current account. Since, its trade balance with the U.S. is positive, in our model, the negative current account balance comes from the negative net income due to the repatriation of multinational profits. Following a contractionary U.S. shock, the decline in the return to transferring production to Mexico, causes a large drop in FDI inflows (i.e., $x^T$, panel 7), a phenomenon that echoes the "sudden stops" literature (e.g. Calvo, 1998). The drop in FDI inflows reduces the ability of the Mexican economy to finance its current account deficit. Despite the reduction in net income outflows (due to the reduction in multinational profits, $\pi^T$), restoring the balance of payments requires the peso to depreciate, and in this way reduce the volume of U.S. exports to Mexico. Hence, the depreciation of the peso that follows a contractionary U.S. shock.

*Response to a Mexican Shock.*– To complete our analysis of the model's impulse responses, we study the effects of Mexican TFP shocks (see Figure 6). There are some striking differences with the response to the U.S. shock. First, a Mexican shock has a very small effect in the U.S. This follows from the difference in size between the two economies. One consequence is that the Mexican shock has a

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smaller when we calibrate higher transport costs so that the volume of trade is smaller.

much smaller effect on U.S. R&D investments than the U.S. shock. As a result, the slowdown in the flow of intermediate goods to Mexico is less protracted than for the U.S. shock (panel 8) generating a less persistent response of Mexican output. This in turn leads to more muted firms' responses in their investment decisions. In particular, the Mexican shock leads to smaller reductions by U.S. firms in the resources they invest in exporting and transferring the production of intermediate goods to Mexico (panel 7). Similarly, Mexican firms respond by cutting domestic investment in physical capital by less (panel 4). As a result, of these differences, the fluctuations in the range of technologies available for production in Mexico is smaller and less protracted in response to the Mexican shock than to the US shock.

## INSERT FIGURE 6 HERE

In addition to the dynamics of technology, another element that dampens the effect of the shock on the Mexican economy is the exchange rate (panel 11). Unlike the U.S. shock, a contractionary TFP shock to Mexico leads to an appreciation of the peso. The response of the real exchange rate affects the behavior of the investment-output ratio in both countries. In Mexico, the investment-output ratio drops less than with the U.S. shock because now Mexican firms can import U.S. intermediate goods more cheaply. In the U.S., the appreciation of the peso makes imported intermediate goods more expensive reducing the effective productivity of the investment sector (panel 6). Firms respond to the higher investment prices by cutting investment a lot (relative to the actual drop in U.S. output) (panel 4). This same logic accounts for the worsening of the Mexican trade balance.

Finally, the last feature of the impulse response functions that deserve attention is the response of domestic interest rates to a Mexican shock. As shown by Neumeyer and Perri (2005), an important feature of business cycles in developing countries is the counter-cyclicality of real interest rates. Our model delivers this result endogenously (panel 5). In our model, the procyclical diffusion of technologies generates counter-cyclical fluctuations in the relative price of capital. This is the case because, as one can see from expression (22), interest rates in our model not only reflect the marginal product of capital but also the capital gains from the appreciation in the price of capital. The pro-cyclical diffusion of technologies induces counter-cyclical capital gains from holding a unit of capital. In the case of the domestic Mexican shock, this second effect dominates the pro-cyclical response of the marginal product of capital (i.e. the dividend), thus inducing interest rates in $S$ (as well as the interest differential with respect to $N$) to be counter-cyclical.

### C.   Simulations

We next turn to the quantitative evaluation of the model. To this end, we calibrate the volatility and persistence of TFP shocks in the U.S. and Mexico and

run 1000 simulations over a 17-year long horizon each. Since we intend to evaluate the model's ability to propagate shocks both internationally and over time, we use the same autocorrelation for both U.S. and Mexican shocks and set the cross-country correlation of the shocks to zero. We set the annual autocorrelation of TFP shocks to 0.8 to match the persistence of output in the U.S.[28]

We calibrate the volatility of the shocks by forcing the model to approximately match the high frequency standard deviation of GDP in Mexico and the U.S. This yields a volatility of the TFP shocks of 2.16% in the U.S. and 3.73% in Mexico. This is consistent with the suspicion that developing economies are prone to bigger disturbances than developed countries.

*Volatility.*– Table 3 compares the standard deviations of the high frequency and medium term cycle fluctuations in the data and in the model. Our calibration strategy forces the model to match the volatilities of output in Mexico and the U.S. at the high frequency. In addition, the model also comes very close to matching the volatility of output over the medium term both in Mexico (0.045 vs. 0.04 in the data) and in the U.S. (0.022 vs. 0.016 in the data). Given the low persistence of shocks, matching these moments suggests that the model induces the right amount of propagation of high frequency shocks into the medium term.

## INSERT TABLE 3 HERE

The model does a good job in reproducing the volatility observed in the data in most variables. In particular, it generates series for investment, bilateral trade flows, and FDI flows that have similar volatilities to those observed in the data both at the high frequency and medium term. For those instances where there are some differences, the empirical volatilities tend to fall within the 95% confidence interval for the standard deviation of the simulated series. The model tends to underpredict the volatility of the relative price of capital, and the extensive margin of trade. We take this as an indication that our calibration of the endogenous diffusion mechanisms does not overstate its importance relative to the data. The variable where the model fails is consumption. The model underpredicts the volatility of consumption in Mexico, especially at the high frequency. This may be a reflection of our model's lack of financial frictions in developing countries which may enhance the volatility of consumption in the data. In the U.S., instead, consumption is about as volatile in the model as in the data.

*Co-movement.*– Most international business cycle models have problems reproducing the cross-country co-movement patterns observed in macro variables. First, they lack international propagation mechanisms that induce a strong positive co-movement in output. Second, they tend to generate a stronger cross-country co-movement in consumption than in output, while in the data we observe

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

the opposite (Backus, Kehoe and Kydland, 1992).[29]

Our model fares well in both of these dimensions. Panel A of Table 4 reports the cross country correlations between Mexico and the U.S. for consumption and output, both in the model and in the data. The model generates the strong co-movement between U.S. and Mexico GDPs observed in the data. The average cross-country correlation in our simulations is 0.72 with a confidence interval of (0.4 , 0.9) that contains the correlation observed in the data (0.423). The model also generates a smaller cross-country correlation for consumption than for output, as we observe in the data: The average cross-correlation is 0.31 with a confidence interval that contains the empirical correlation (0.37).[30]

<center>INSERT TABLE 4 HERE</center>

The endogenous diffusion of technology contributes to generating this cross-country co-movement pattern. Intuitively, the endogenous diffusion of technology generates a strong cross-country co-movement in output and productivity over the medium term. Anticipating the future evolution of the economy, Mexican firms adjust investment contemporaneously. The large effect that foreign shocks have on domestic investment limits the possibility for a large consumption response, hence inducing a higher cross-country correlation in output than in consumption.

Panel B of Table 4 reports the contemporaneous correlation between the HP-filtered Mexican variables and HP-filtered output in both Mexico and the U.S.[31] Broadly speaking, the model does a good job in capturing the contemporaneous co-movement patterns within Mexico but also between Mexico and the U.S. The model generates a positive, albeit insignificant correlation between consumption and output in Mexico (0.47 vs. 0.77 in the data). Also, in both model and data, Mexico's consumption is more correlated with Mexico's GDP than with the U.S. The model captures the strong co-movement between Mexican investment and output in both the U.S. (0.78 vs. 0.51 in the data) and Mexico (0.99 vs. 0.61 in the data). In our model, the pro-cyclical response of investment is in part due to the counter-cyclicality of the relative price of investment. Our model approximately matches the co-movement between Mexico's output and the price of new capital (-0.8 vs. -0.49 in the data), although it overstates the co-movement between the price of capital in Mexico and U.S. GDP (-0.9 in model vs. 0.23 in data). Similarly, recall that the medium term productivity dynamics in Mexico

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

[30]The international business cycle literature has also found it difficult to generate positive cross-correlations in investment and employment (Baxter, 1995). As it is clear from Figure 4, our model delivers both.

[31]Note that we do not filter the growth rate of intermediate goods since this variable is already trend stationary.

result from the cyclicality of the flow of intermediate goods that diffuse to Mexico (i.e. the extensive margin of trade). The model matches does a decent job in terms of the cyclicality of this variable both with respect to U.S. output (0.42 vs. 0.21 in the data) and to Mexico's (0.36 vs. 0.39 in the data).

The model also captures broadly the cyclicality of the bilateral trade flows. In particular, the model generates the strong counter-cyclicality of Mexico's trade balance. The correlation between Mexico's trade balance and GDP is -0.96 vs. -0.69 in the data. This is the case because, both in our model and (especially) in the data, imports from the U.S. co-move more with Mexico's GDP than exports to the U.S. However, the model overpredicts the cyclicality of Mexican exports to the U.S. (with respect to Mexican GDP). The model approximately captures the high correlation of bilateral trade flows with U.S. GDP.

A variable where the model underperforms is FDI. In particular, FDI is more pro-cyclical in the model than in the data. This may reflect the presence of a small but volatile component in actual FDI that does not respond to the U.S. or Mexican business cycle. This hypothesis seems to be supported by the fact that FDI is also much more persistent in our model than in the data.[32]

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

<div align="center">INSERT TABLE 5 HERE</div>

The model captures the contemporaneous correlation between high frequency fluctuations in U.S. output and medium term fluctuations in Mexico's output (0.33 in the model vs. 0.36 in the data). The model also generates the hump-shaped cross-correlogram between these two variables we observe in the data with a peak correlation after one year (0.37 in the model vs. 0.47 in the data).

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

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[32]In particular, the annual autocorrelation of FDI/GDP in our model is 0.42 while in the data it is -0.35.

after one year (-0.44), while in the actual data it is reached after three years (-0.53).

Unlike U.S. shocks, Mexican shocks do not have a hump-shaped effect on Mexico's output over the medium term fluctuations. The correlation between HP-filtered and the medium term component of Mexico's output is positive and declines monotonically as we lag the series of HP-filtered output.[33] Our model is consistent with this co-movement pattern. (See rows 5 through 8 in Table 5.)[34]

## V.    Discussion

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

*Other Shocks.–* For concreteness, we have used TFP shocks as the sole source of fluctuations in our simulations. However, our findings are not driven by the nature of the shocks. To illustrate this, we introduce shocks to the wage markup and to the price of investment. Figure 7 presents the impulse response functions to a (positive) wage markup shock (second row) and a (positive) shock to the price of investment (third row) both in the U.S. To facilitate the comparison, the impulse response function to the U.S. TFP shock is presented in the first row of the figure.

## INSERT FIGURE 7 HERE

Qualitatively, the impulse response functions to these shocks are very similar. In all of them there is a large effect upon the impact of the U.S. shock on Mexican output. All shocks generate a hump-shaped response of Mexico's output. And in all three cases, the U.S. shock eventually has a larger effect on Mexico than in the U.S. The economics of the response are the same as in the TFP shock described above. All three shocks trigger a large and persistent slowdown in the flow of new technologies to Mexico and an initial decline in Mexico's investment larger than the initial decline in consumption. As the productivity of the capital goods sector deteriorates relative to trend, investment declines further generating the hump in the output response. The response to Mexican shocks is also robust to the nature of the shocks (see Figure A2).

*Sunk vs. Fixed Exporting Costs.–* Much of the theoretical international macro literature that has incorporated the extensive margin of trade has relied on extensions of the Melitz (2003) model. The Melitz model is a two country model with firms of heterogeneous productivity and where firms have to incur in some costs to export. Unlike our model, most of the models that have used the Melitz

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[33]In the working paper version, we make a similar point by estimating VARs with HP-filtered Mexico's GDP and the medium term component of several Mexican variables (including GDP).

[34]A similar (but negative) co-movement patter is generated in the model between HP-filtered output and the medium term component of the relative price of capital in Mexico. In the data the co-movement between these variables is also negative but insignificant. (See rows 7 and 8 in Table 5.)

framework to explore business cycle dynamics use fixed cost instead of sunk cost to adjust the range of intermediate goods available for production.

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

Figure 8 plots the impulse response functions to a (negative) TFP shock in the U.S. in the model with fixed costs. The differences with our original model are remarkable. In the model with fixed costs of exporting and FDI, a contractionary U.S. shock causes no effect in Mexico's output upon impact. The sharp contrast between the responses in figures 4 and 7 is ultimately due to the different nature of the costs of technology diffusion in the two models. With the fixed costs of exporting and transferring technologies, the stock of technologies in $S$ depends on the profits accrued by local, global and transferred intermediate goods and on the exchange rate. Since all these are jump variables, this means that $A^g$ and $A^T$ are no longer state variables. As a result, investments in exporting and transferring production no longer have persistent effects on the productivity level in $S$. As a result, productivity in $S$ fluctuates less over the medium term, generating also a more muted response of the relative price of capital. Anticipating smaller increases in the price of investment and smaller drops in future demand, Mexican firms undertake smaller cuts in their investment, upon impact. The smaller response of investment in Mexico has two significant feedback effects. First, it leads to a smaller drop in the profits accrued by intermediate goods producers in Mexico, further dampening the response of investments in technology diffusion. Second, the smaller drop in Mexican investment implies that now Mexican net exports are counter-cyclical, while with the sunk cost formulation they responded pro-cyclically to U.S. shocks. As a result, in response to a contractionary shock to U.S. TFP, net exports increase dampening further the impact on Mexican output of the shock.

*Implications for Aggregate Volatility.–* It is clear from Figure 4 that U.S. shocks are a significant source of volatility in Mexico's GDP. But what share of Mexican fluctuations is due to U.S. shocks and what share is due to domestic shocks? Similarly, how much do Mexican shocks contribute to the volatility of U.S. GDP?

Table 6 answers these questions by reporting the share of output volatility in

each country attributable to each kind of shock. The first two columns focus on the volatility of HP-filtered output while the next two focus on the volatility of output over the medium term cycle. Consistent with Figure 6, Mexican shocks account for a small fraction of U.S. fluctuations (10% at high frequency and 11% over the medium term cycle).

<div align="center">INSERT TABLE 6 HERE</div>

In contrast, U.S. shocks represent a very significant source of Mexican fluctuations. At the high frequency, 65% of Mexico's GDP volatility is driven by U.S. shocks, while over the medium term cycle, U.S. shocks induce 69% of the volatility in Mexico's GDP. This proves the importance of explicitly modelling the U.S. economy to study the business and medium term cycles of the Mexican economy.

## VI.   Conclusions

In this paper we develop an asymmetric two-country model to study business cycle fluctuations in developing countries. The model introduces two key elements. First, productivity growth in $N$ is endogenous and results from the creation of new intermediate goods through R&D. Second, firms in $N$ face a sunk cost of exporting intermediate goods to $S$ and transferring the production of the intermediate goods to $S$. These mechanisms yield four predictions consistent with the macroeconomic cycles of developing countries.

First, business cycle shocks to developed economies have large effects on developing economies. Second, these effects are persistent, inducing fluctuations at frequencies lower than the conventional business cycle. Third, the cross-country correlation of output between developed and developing countries is higher than that of consumption. Fourth, interest rates are counter-cyclical in developing countries. After calibrating the model to the U.S. and Mexican economies, we find that the model also does a good job quantitatively. Its main shortcoming is the inability to generate a consumption series in developing countries that is as volatile as in the data. One possible avenue to achieve this is by introducing financial frictions in developing countries that may limit consumption smoothing.

One of the key contributions of this paper is to extend the business cycle models of endogenous technology (Comin and Gertler, 2006) to two-country settings. There are several alternative configurations of the two countries that are worth pursuing in future research. One natural variation is to model both countries as advanced economies that develop new technologies through R&D and adopt each other's technologies. This configuration would naturally capture the interactions between the U.S. and the EU or the U.S. and Japan, for example. A second variation could be to keep the asymmetry between the developed and developing countries but introduce low frequency transitions in the developing country to its balanced growth path. This configuration would be helpful to analyze the interdependence between, say, the U.S. and China at high and medium term frequencies.

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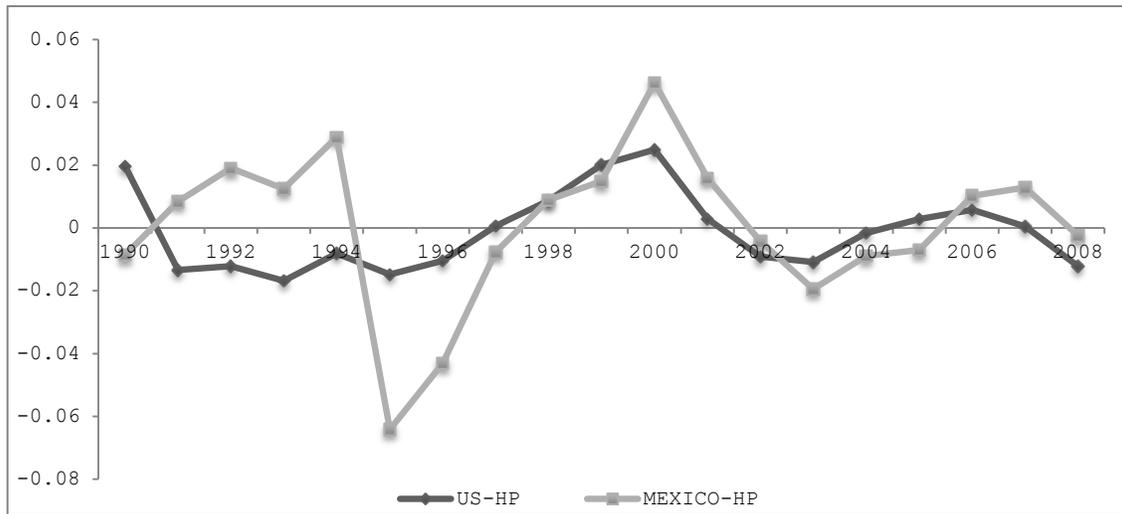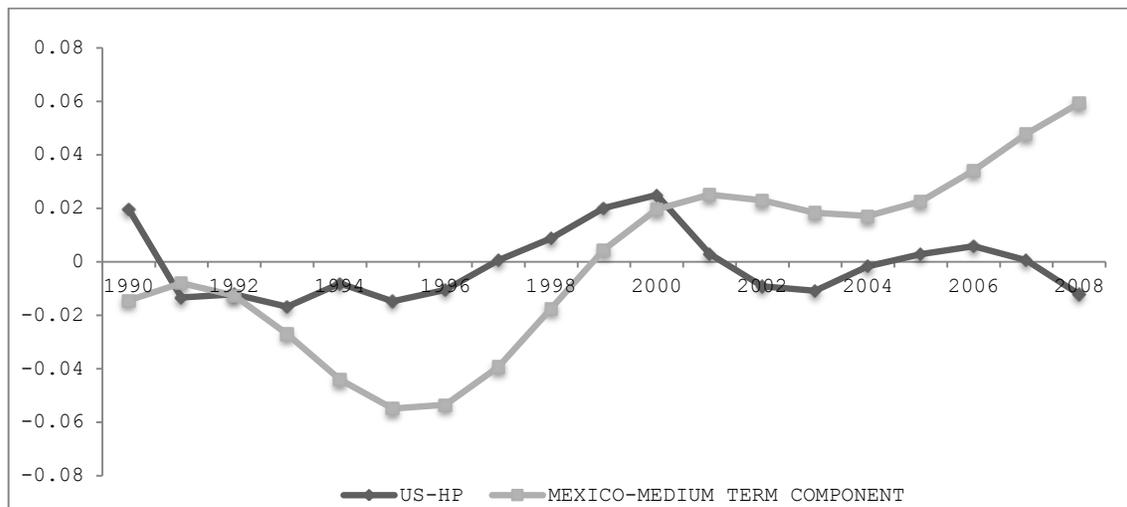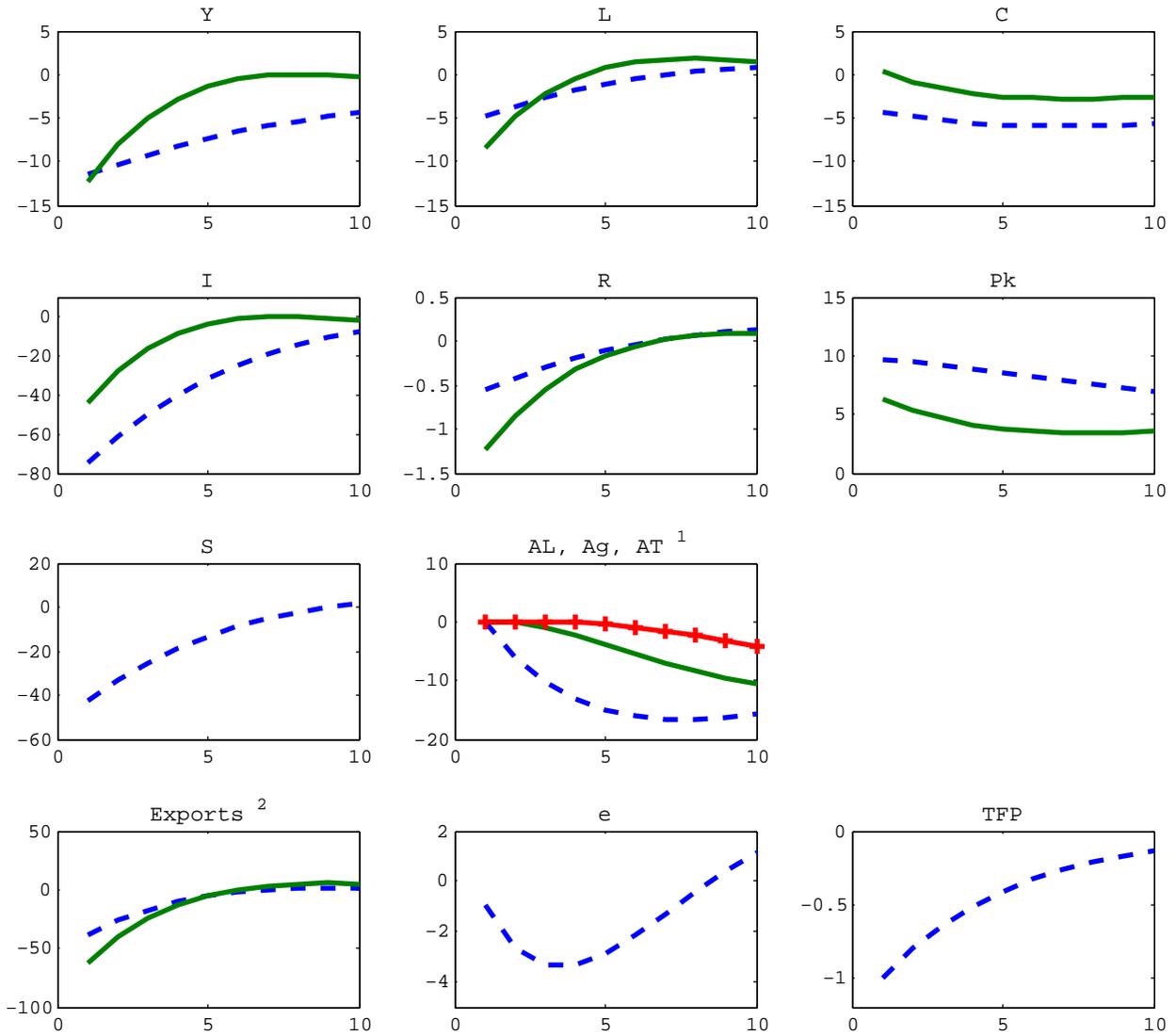in Mexico and the US



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



Source: World Development Indicators, Authors' calculations

Figure 2: Impulse Response Functions to Negative U.S. TFP Shock,
Model Without International Technology Flows (U.S.Dash, Mexico, solid)



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

[2] US Exports (--), Mexico Exports (-)

Figure 3: Impulse Response Functions to Negative U.S. TFP Shock
Model Without International Technology Flows and Correlated TFP Shocks (U.S.Dash, Mexico, solid)
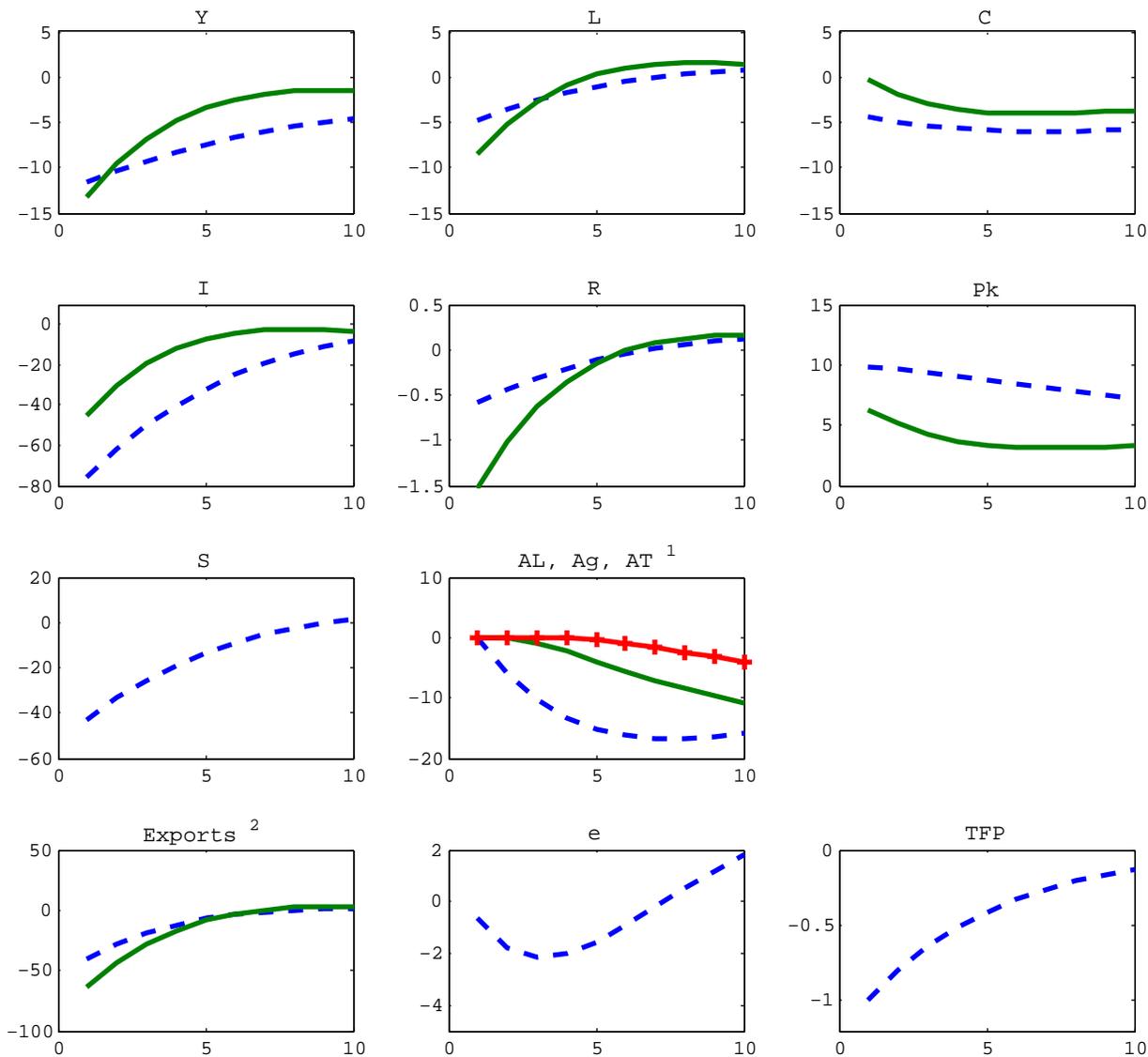


[1] Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transfered Intermediate Goods(AT,-
[2] US Exports (--), Mexico Exports (-)

Figure 4: Impulse Response Functions to Negative U.S. TFP Shock,
Endogenous Technology Diffusion (U.S.Dash, Mexico, solid)
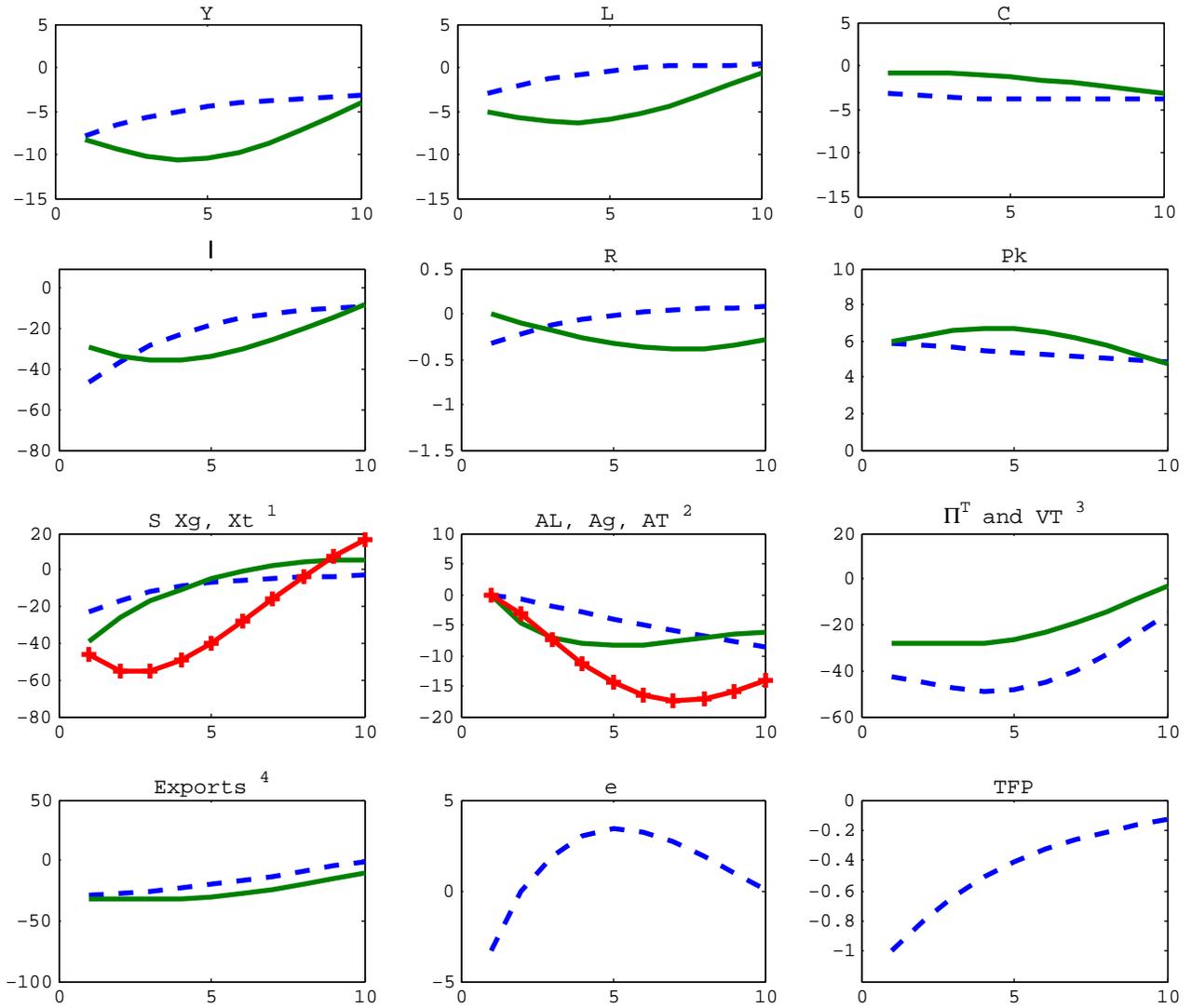


[1] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)
[2] Local Intermediate Goods (AL,--), Exported Intermediate Goods(Ag,-) and Transfered Intermediate Goods(AT,-+)
[3] Net income from transferred intermediate goods (--), Value of transferred intermediate goods (-)
[4] US Exports (--), Mexico Exports (-)

Figure 5: Impulse Response Functions to Negative U.S. TFP Shock Pre–NAFTA, Endogenous Technology Diffusion(U.S.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 (-)

[4] US Exports (--), Mexico Exports (-)

Figure 6: Impulse Response Functions to Negative Mexico TFP Shock,
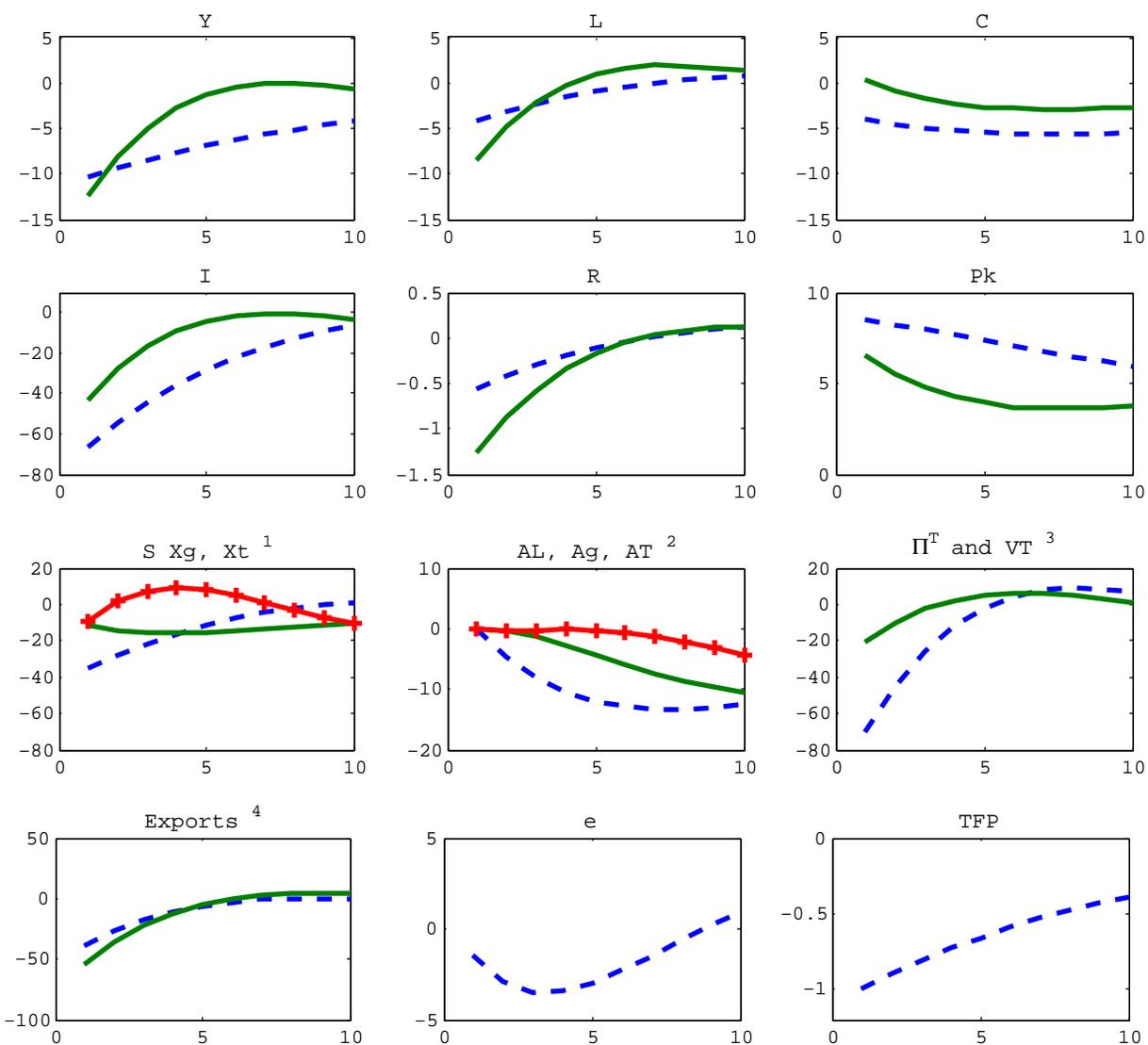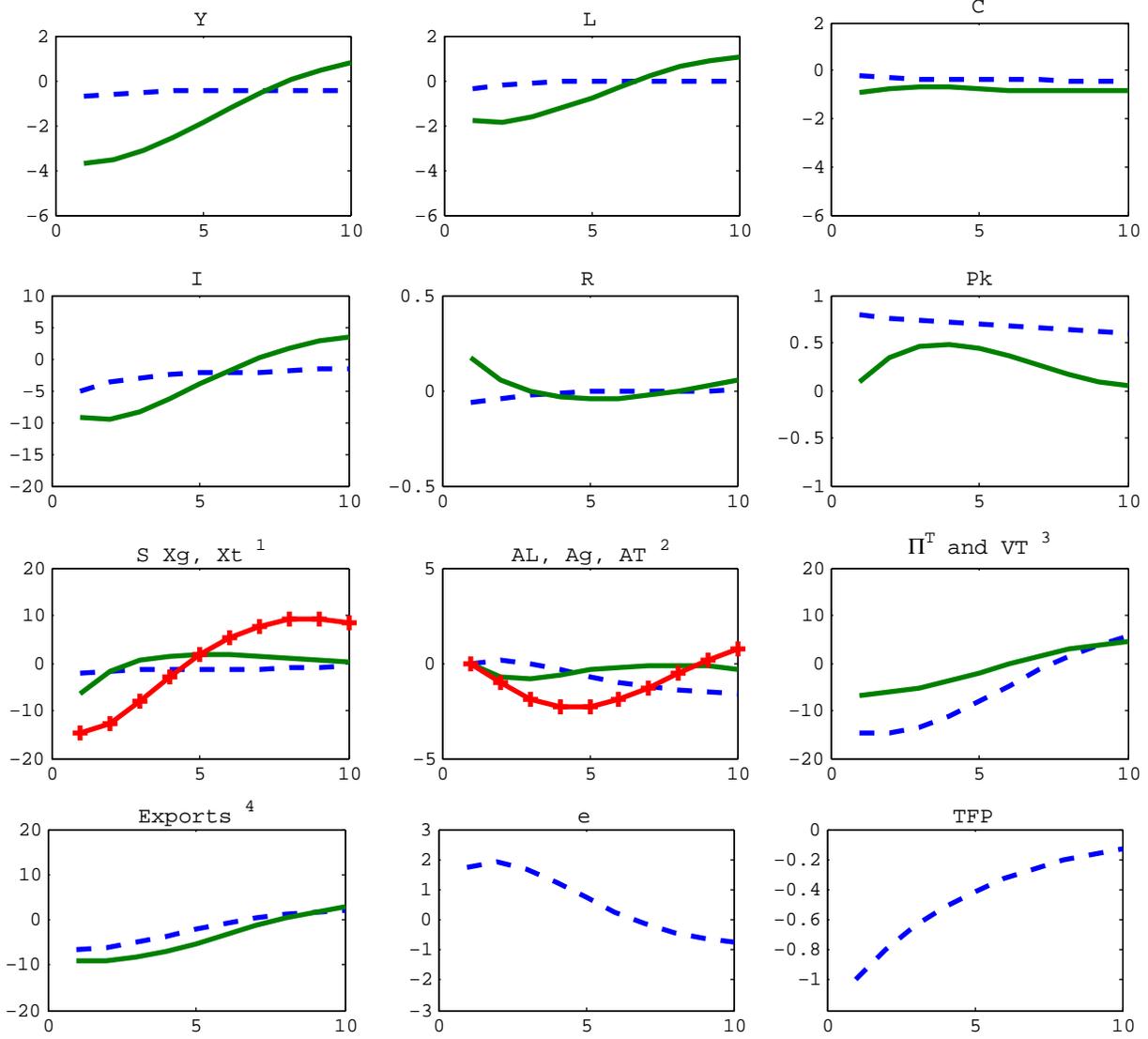Endogenous Technology Diffusion (U.S.Dash, Mexico, solid)



[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 (-)
[4] US Exports (--), Mexico Exports (-)

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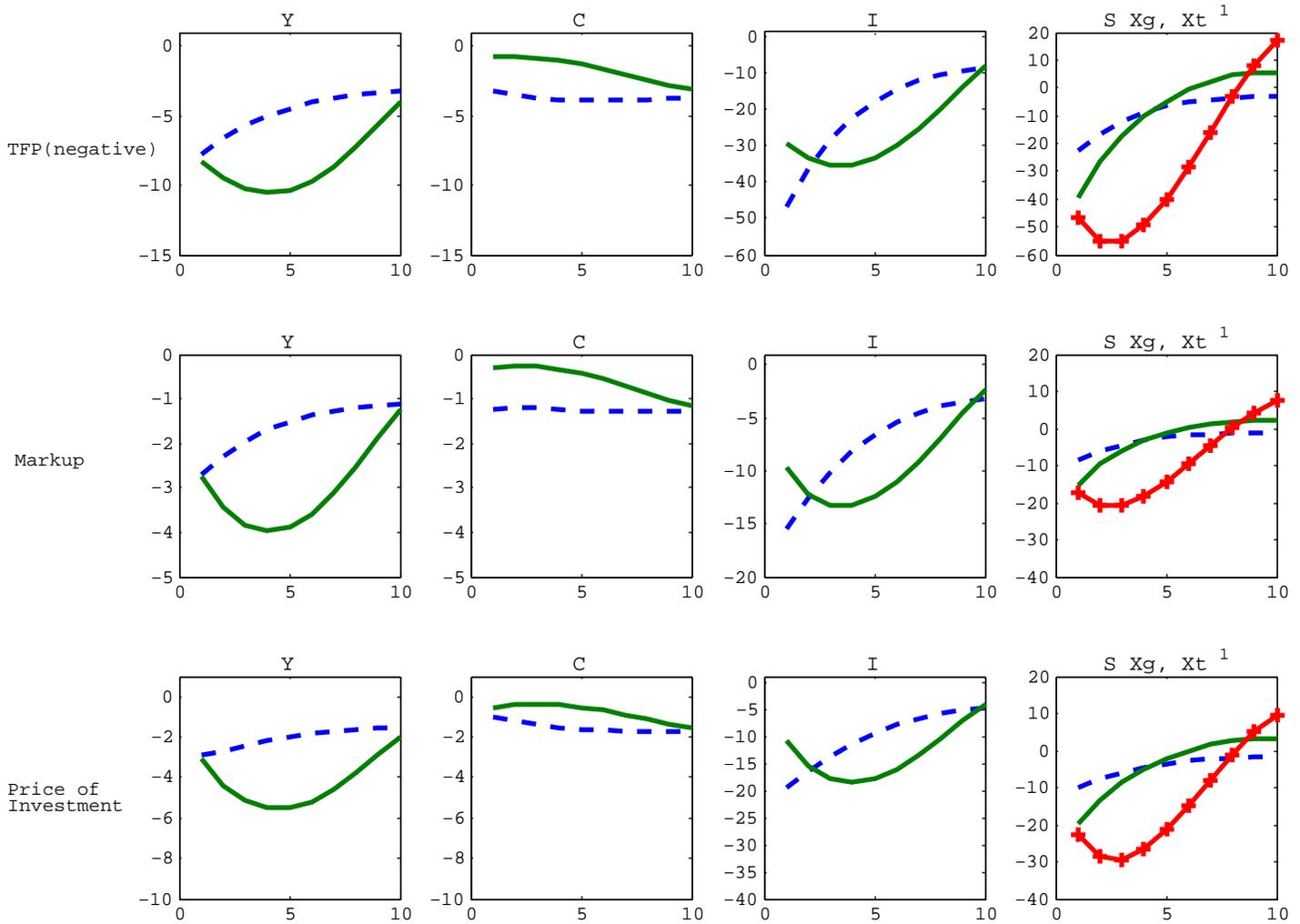


[1] Research and development expenditures (S, --), investments in exporting (Xg,-) and FDI (Xt, -+)

Table 1A: High and medium term effects on developing economies of high frequency fluctuations in developed economies

| | Lags | Developed GDP (HP-filtered) | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Period: 1990-2008 | | | | | |
| Developing GDP (HP-filtered) | | 0.43 *** | 0.29 *** | 0.11 | 0.05 |
| Developing GDP (Medium Term Component) | | 0.63 *** | 0.76 *** | 0.61 *** | 0.39 |
| Period: 1975-1990 | | | | | |
| Developing GDP (HP-filtered) | | 0.12 | 0.20 | 0.22 | 0.12 |
| Developing GDP (Medium Term Component) | | -0.71 *** | -0.45 | -0.17 | -0.02 |

Note: Coefficients of univariate regression: GDP Developing on GDP Developed. Significance level determined using robust standard errors.

Table 1B: Cyclicality of imported varieties durable manufacturing

| | Developed GDP (HP filtered) | Developing GDP (HP filtered) |
|---|---|---|
| Varieties imported from Developed (HP-filtered) | 0.17 *** | 0.62 *** |
| Varieties imported from Developed (Medium term business cycle) | 0.12 ** | 0.56 *** |

Note: Correlation Coefficients. Imported varieties are measured as number of 6-digit SIC categories in durable manufacturing with Developed exports to Developing with value greater that $1 Million.

Table 1C: Medium term correlation between varieties imported from developed economy and relative price of capital and GDP in developing

| | Lags | Durable manufacturing varieties imported from developed country | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| GDP developing country | | 0.15 *** | 0.17 *** | 0.12 ** | 0.03 |
| Relative price of capital developing country | | -0.16 *** | -0.25 *** | -0.31 *** | -0.32 *** |

Note: All series are filtered using a Band-Pass filter that isolates frequencies between 8 and 50 years. Relative price of capital defined as the investment deflator over the GDP deflator.

Notes for Tables 1A-1C: * significant at 10%, ** at 5%, *** at 1%. Medium Term Component is filtered using a Band Pass filter that isolates cycles with period between 8 and 50 years. The developing countries linked to the US are Mexico, Dominican Republic, Costa Rica, Paraguay, Honduras, Guatemala, Venezuela, Peru, El Salvador and Nicaragua. The countries linked to Japan are Panama, Thailand, South Korea, Philippines, Vietnam, China, Pakistan, Indonesia, South

Table 2: Calibration

| Parameter | Target | Value |
|---|---|---|
| **Standard** | | |
| $\alpha$ | Labor income = 0.66 | 0.33 |
| $\beta$ | Investment share = 0.22 | 0.95 |
| $\delta$ | 0.1, (BEA) | 0.1 |
| $U$ | 0.8, (U.S. Board of Bovernors) | 0.8 |
| $\delta''(U) * U/\delta'(U)$ | 0.15, (Jaimovich & Rebelo, 2006) | 0.15 |
| $\zeta$ | Share of hours worked = 0.4 | 0.5 |
| $\mu_c$ | 1.1, (Basu and Fernald, 1997) | 1.1 |
| $\mu_k$ | 1.15, (Basu and Fernald, 1997) | 1.15 |
| $L_N/L_S$ | Relative population =3 | 3 |
| $Z_{0N}/Z_{0S}$ | Relative GDP = 12 | 3.35 |
| $g$ | Productivity Growth = 0.024 (BLS) | 0.0072 |
| **R&D** | | |
| $\phi$ | 0.1, (average of Caballero & Jaffe, Pakes & Schankerman, ) | 0.9 |
| $b_c$ | Aggregate overhead costs = 10% GDP | 0.05 |
| $b_c^k$ | Measure of final capital firms =1 | 0.016 |
| $\chi$ | Growth relative price capital = -0.026 | 2.69 |
| $\theta$ | Share of R&D in durable manufacturing = 1% | 1.5 |
| $\rho$ | 0.65, (Griliches, 1990) | 0.65 |
| **Trade and Diffusion** | | |
| $\xi$ | 2, (Iyer, 2003) | 2 |
| $\psi$ | Mexican imports from US = 14% Mexico GDP | 0.95 |
| $\lambda^g$ | Value weighted share of US firms that export = 0.33 | 0.0875 |
| $\lambda^T$ | Mexican exports to US = 20% Mexico GDP | 0.0055 |
| $\rho^g$ | Sunk costs of exporting = 0.3, (Das et al., 2007) | 0.8 |
| $\rho^T$ | US FDI/ Mexico GDP = 0.02 | 0.5 |

Table 3 : Volatility Model vs. Data

| | High Frequency | | Medium term Cycle | |
|---|---|---|---|---|
| MEXICO | Data | Model | Data | Model |
| GDP | 0.025 | 0.024 (0.020, 0.042) | 0.040 | 0.045 (0.029, 0.073) |
| CONSUMPTION | 0.027 | 0.003 (0.003, 0.005) | 0.039 | 0.009 (0.006, 0.014) |
| INVESTMENT | 0.075 | 0.079 (0.067, 0.138) | 0.079 | 0.149 (0.096, 0.242) |
| RELATIVE PRICE OF CAPITAL | 0.036 | 0.012 (0.011, 0.016) | 0.035 | 0.023 (0.017, 0.031) |
| IMPORTS (FROM US) | 0.085 | 0.076 (0.065, 0.121) | 0.114 | 0.141 (0.086, 0.215) |
| EXPORTS (TO US) | 0.084 | 0.065 (0.059, 0.098) | 0.142 | 0.110 (0.075, 0.168) |
| TRADE SUPLUS/GDP | 0.013 | 0.014 (0.013, 0.024) | 0.048 | 0.026 (0.018, 0.042) |
| GROWTH IN INTERMEDIATE GOODS EXPORTED FROM US TO MEXICO | 0.049 (all) | 0.01 (0.006, 0.014) | | |
| FDI/GDP | 0.003 | 0.003 (0.003, 0.005) | 0.007 | 0.012 (0.007, 0.019) |
| U.S. | | | | |
| GDP | 0.013 | 0.015 (0.014, 0.016) | 0.016 | 0.022 (0.018, 0.025) |
| CONSUMPTION | 0.009 | 0.006 (0.006, 0.007) | 0.013 | 0.013 (0.011, 0.015) |
| INVESTMENT | 0.066 | 0.089 (0.088, 0.097) | 0.114 | 0.129 (0.101, 0.142) |

Note: Period 1990-2008. High frequency corresponds to cycles with periods lower than 8 years and is obtained by filtering simulated data with a Hodrick-Prescott filter. Medium term cycles corresponds to cycles with periods shorter than 50 years and is obtained by filtering simulated data with a Band-Pass filter. The relative price of capital is the investment deflator divided by the GDP deflator. Growth in intermediate goods is not filtered. All stands for all manufacturing sectors while dur stands for durable manufacturing.

Table 4: Contemporaneous Co-movement patterns

PANEL A: Cross-country correlations between Mexico and U.S.

|  | Data | Model |  |
| --- | --- | --- | --- |
| GDP | 0.42* | 0.72 |  |
|  |  | (0.40, 0.90) |  |
| CONSUMPTION | 0.37 | 0.31 |  |
|  |  | (-0.23, 0.72) |  |

PANEL B: Correlation of Mexican Macro Variables with Mexican and U.S. GDP

|  | GDP USA | | GDP MEXICO | |
| --- | --- | --- | --- | --- |
|  | Data | Model | Data | Model |
| CONSUMPTION | 0.06 | 0.35 | 0.77*** | 0.47 |
|  |  | (-0.18, 0.75) |  | (-0.15, 0.87) |
| INVESTMENT | 0.51** | 0.78 | 0.61*** | 0.99 |
|  |  | (0.53, 0.92) |  | (0.97, 1.00) |
| RELATIVE PRICE OF CAPITAL | 0.23 | -0.90 | -0.49*** | -0.80 |
|  |  | (-0.96, -0.83) |  | (-0.95, -0.52) |
| IMPORTS (FROM US) | 0.55** | 0.84 | 0.83*** | 0.98 |
|  |  | (0.62, 0.96) |  | (0.94, 0.99) |
| EXPORTS (TO US) | 0.69*** | 0.91 | 0.08 | 0.92 |
|  |  | (0.79, 0.98) |  | (0.83, 0.97) |
| MEXICAN TRADE SURPLUS/GDP | 0.05 | -0.73 | -0.69*** | -0.99 |
|  |  | (-0.90, -0.42) |  | (-1.00, -0.98) |
| GROWTH IN INTERMEDIATE GOODS | 0.11 (all) | 0.42 | 0.33 (all) | 0.36 |
|  |  | (0.05, 0.74) |  | (-0.02, 0.68) |
| FDI/GDP | 0.28 | 0.78 | 0.08 | 0.87 |
|  |  | (0.54, 0.92) |  | (0.70, 0.97) |

Note: Period 1990-2008. All variables but FDI are scaled by working age population in Mexico. All variables other than growth of intermediate goods have been HP-filtered. The model statistics are the average of the contemporaneous cross-correlations from the Monte Carlo consisting of 1000 17-year long simulations. In parenthesis 95 percent confidence intervals. The relative price of capital is measured by the investmentd eflator over the GDP deflator.All stands for all manufacturing sectors while dur. stands for durable manufacturing. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

## Table 5: Cross-Correlogram Across Frequencies

| | Lags of High Frequency US Output | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| MEDIUM TERM COMPONENT MEX GDP | | | | |
| Data | 0.36 | 0.47* | 0.44* | 0.25 |
| Model | 0.33** | 0.37** | 0.33** | 0.20** |
| MEDIUM TERM COMPONENT RELATIVE PRICE OF CAPITAL IN MEX | | | | |
| Data | 0.28 | 0.03 | -0.30 | -0.53** |
| Model | -0.39 | -0.44 | -0.36** | -0.21 |
| | Lags of High Frequency MEX Output | | | |
| | 0 | 1 | 2 | 3 |
| MEDIUM TERM COMPONENT MEX GDP | | | | |
| Data | 0.68*** | 0.29 | -0.05 | -0.28 |
| Model | 0.64** | 0.59** | 0.40 | 0.15** |
| MEDIUM TERM COMPONENT RELATIVE PRICE OF CAPITAL IN MEX | | | | |
| Data | -0.52** | -0.34 | -0.21 | -0.17 |
| Model | -0.54** | -0.50** | -0.36** | -0.15** |

Note: Period 1990-2008. High frequency corresponds to cycles with periods lower than 8 years and is obtained by filtering simulated data with a Hodrick-Prescott filter. Medium term cycles corresponds to cycles with periods lower than 50 years and is obtained by filtering simulated data using a Band-Pass filter. The reported measures are the average of the contemporaneous cross correlations from the Monte Carlo consisting of 1000 17-year long simulations. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level..

Table 6: Decomposition of output volatility

|  | High Frequency | | Medium Term Cycle | |
|---|---|---|---|---|
|  | US volatility | Mexican volatility | US volatility | Mexican volatility |
| US Shocks | 0.90 | 0.65 | 0.89 | 0.69 |
| Mexico Shocks | 0.10 | 0.35 | 0.11 | 0.31 |

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.