

Offshore Production, Labor Migration and the Macroeconomy

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Boston College

The Graduate School of Arts and Sciences

Department of Economics

OFFSHORE PRODUCTION, LABOR MIGRATION

AND THE MACROECONOMY

a dissertation

by

ANDREI ZLATE

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OFFSHORE PRODUCTION, LABOR MIGRATION
AND THE MACROECONOMY

- Dissertation Abstract -

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In my doctoral dissertation, I examine theoretical and empirical questions related to the international macroeconomic effects of offshore production, labor migration and remittances.

In Chapter 1, "*Offshore Production and Business Cycle Dynamics with Heterogeneous Firms*," I analyze the cross-country transmission of business cycles when firms relocate production abroad at locations with relatively lower labor costs, an action which I refer to as offshoring. In the model, I distinguish between fluctuations in the number of firms producing offshore (the extensive margin) and the value added per offshoring firm (the intensive

margin) as separate transmission mechanisms. Firms are heterogeneous in labor productivity; they face a sunk entry cost in the domestic market and an additional fixed cost to produce offshore. The incentive to relocate production abroad increases with the difference between the domestic and foreign cost of effective labor, and with firm-specific productivity. The key results are: (1) The model replicates the procyclical pattern of offshoring, as well as the extensive and intensive margin dynamics that I document using data from Mexico's *maquiladora* sector; (2) Offshoring enhances the co-movement of output between the countries involved; and (3) Offshoring reduces price dispersion across countries, because it dampens the real exchange rate appreciation that follows a productivity increase in the parent country.

In Chapter 2, "*Offshore Production to Mexico: The Intensive and Extensive Margin Responses to U.S. Technology Shocks*," I estimate the conditional correlations and impulse responses of three indicators of offshoring to Mexico (total value added, value added per plant, and the number of plants) associated with U.S. permanent technology shocks. Using data from U.S. manufacturing and Mexico's *maquiladora* sector, I identify U.S. permanent technology shocks in an open-economy, structural VAR model with long-run restrictions. I find that: (1) Offshore production in Mexico exhibits an imme-

diate increase along its intensive margin (value added per plant) in response to a positive U.S. technology shock, but returns to its initial level over time. In contrast, the extensive margin (the number of plants) does not adjust on impact, but increases gradually over time and stabilizes at a permanently higher level. (2) In the presence of country-specific technology shocks, the model of offshoring with heterogeneous firms in Chapter 1 matches qualitatively the business cycle dynamics of offshoring from the U.S. to Mexico.

In Chapter 3, "*Immigration and the Macroeconomy*" (co-authored with Federico Mandelman), we analyze the dynamics of labor migration and the insurance role of remittances in a two-country, real business cycle framework. Emigration increases with the expected stream of future wage gains, and is dampened by the sunk cost reflecting the intensity of border enforcement. During booms in the destination economy, the scarcity of established immigrants lessens capital accumulation, and enhances the volatility of the immigrant wage and remittances. The welfare gain from the inflow of unskilled labor increases with the complementarity between skilled and unskilled labor, and with the share of the skilled among native labor. The model matches the cyclical dynamics of both the unskilled immigration into the U.S. and remittances sent back to Mexico.

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Chapter 1

Offshore Production and Business Cycle Dynamics with Heterogeneous Firms

*Job Market Paper, November 2008*¹

1.1 Introduction

Firms often follow strategies that involve the fragmentation of production chains and the establishment of foreign affiliates at locations with relatively lower labor costs, an activity known in the international trade literature as offshoring through vertical foreign direct investment (FDI) (Helpman, 1984).² Unlike production under horizontal FDI - which means that foreign affiliates attempt to gain market access by replicating the operations of their parent firms in the country where final consumption takes place - the type of vertically-integrated production that I model is primarily motivated by lower production costs, as

¹*JEL classification:* F41, F23; *Keywords:* offshore production, extensive and intensive margins, business cycle dynamics, vertical FDI, heterogeneous firms, firm entry, terms of labor, real exchange rate.

²The term "offshoring" refers to the activity of firms that relocate certain stages of their production to foreign countries. To this end, firms become integrated across borders through vertical or/and horizontal FDI, or purchase intermediate goods and services from unaffiliated foreign suppliers. In contrast, "outsourcing" applies to situations when firms purchase intermediates from unaffiliated suppliers - either at home or abroad - rather than producing them in house. See Helpman (2006) for a discussion of the related literature.

foreign affiliates add value to the final goods that are ultimately sold for consumption in the multinationals' country of origin or in third countries.³ The number of offshoring firms (which I refer to as the extensive margin of offshore production) and the real value added per offshoring firm (the intensive margin) fluctuate over the business cycle, and thus affect output, prices and wages in both the parent and the host countries.⁴

This paper contributes to the international macroeconomics literature by analyzing the extensive and intensive margins of offshoring as separate transmission mechanisms of business cycles between the parent and the host country. I model offshoring as an endogenous, firm-level decision that depends on the difference between the domestic and the foreign cost per unit of effective labor, the fixed cost of offshore production, and the trade cost of shipping output back to the parent country. Fluctuations in the number of offshoring firms are linked to domestic firm entry and to the resulting changes in the relative cost of effective labor. Thus, an increase in aggregate productivity in the parent country encourages domestic firm entry and causes domestic wages to rise faster than productivity, as labor demand increases to cover entry requirements. In turn, the increase in the domestic cost of effective labor causes more firms to relocate production offshore (i.e. an increase in offshoring along its extensive margin).⁵ The increase in the number of offshoring firms is gradual, as it mirrors the gradual appreciation of the cost of effective labor generated by

³Helpman, Melitz and Yeaple (2004) model horizontal FDI and exports as alternative internationalization strategies for multinational firms; Contessi (2006) analyzes this tradeoff in a dynamic framework.

⁴Bergin, Feenstra and Hanson (2008) analyze the extent to which fluctuations in the extensive margin of offshoring account for variations in Mexico's maquiladora employment. They show that more than one third of the adjustment in industry-level employment and nearly half of the adjustment in maquiladora's total employment occur at the extensive margin, i.e. through variation in the number of plants over time.

⁵I maintain a one-to-one identification between an offshoring firm, a final good variety, and an offshore plant. Under this assumption, the extensive margin of offshoring can also be interpreted as the number of offshore plants every period; the intensive margin can be regarded as the value added per offshore plant.

domestic firm entry.

I document a set of stylized facts that characterize the cyclicity of offshoring from U.S. manufacturing to Mexico's *maquiladora* sector.⁶ Using the number of maquiladora establishments as an empirical proxy for the extensive margin, I find that the value added offshore is procyclical with U.S. manufacturing output, and also that the extensive margin varies notably over the business cycle (Figure 6). In particular, I show that expansions in U.S. output precede increases in the number of maquiladora establishments by at least three quarters, a result that highlights the inter-temporal link between U.S. manufacturing and the extensive margin of offshoring.

Despite the empirical evidence, the theoretical macroeconomic literature does not fully capture the business cycle dynamics of offshoring along its extensive and intensive margins. For instance, Burstein, Kurtz, and Tesar (2008) examine the role of production sharing in the transmission of business cycles in a two-country model in which the location of plants is fixed over time.⁷ Bergin, Feenstra, and Hanson (2007) also focus on the importance of offshore production in amplifying the transmission of shocks across countries, but they do so with a model in which the number of offshoring firms makes an abrupt shift rather than a gradual adjustment over time (as I find in the data) in response to aggregate shocks.

I address these deficiencies by incorporating the endogenous determination of the num-

⁶Mexico's *maquiladora* sector consists of manufacturing plants that import intermediate goods, process them, and export the resulting output (Gruben, 2001). Although not entirely owned by U.S. multinationals, most of the maquiladora plants accommodate the offshoring operations of U.S. firms: They import most of their inputs (82 percent) and send most of their gross output (90 percent) from/to the U.S. (Hausman and Kaytko, 2003; Burstein, Kurtz and Tesar, 2008). The maquiladora sector accounts for 20 percent of the Mexico's manufacturing value added (INEGI), nearly 50 percent of the Mexico's exports, and approximately 25 percent of Mexico's employment (Bergin, Feenstra, Hanson, 2007, 2008).

⁷In Burstein, Kurtz and Tesar (2008), the low elasticity of substitution between the domestic and foreign varieties in an Armington composite enhances the cross-country co-movement of output.

ber of offshoring firms in a two-country (North and South), dynamic stochastic general equilibrium (DSGE) model with firm entry and firm heterogeneity, along the lines of Melitz (2003) and Ghironi and Melitz (2005). Firm entry is subject to a sunk cost reflecting the regulation of starting a business in the country of origin. Following entry, each firm can use either domestic or foreign inputs in the production of a different variety of final goods. The use of foreign inputs involves the establishment of an offshore production plant and is subject to a fixed offshoring cost every period. Also, offshoring involves the so-called iceberg trade costs that reflect transportation, insurance, and trade barriers, costs incurred in the shipping of final good varieties produced offshore back to the country of origin. Thus, when deciding on where to locate production (domestically vs. offshore), each firm balances the lower foreign costs of effective labor against the fixed and trade costs associated with offshore production.⁸ Since firms are heterogeneous in productivity, the decision to produce offshore is firm-specific: Only the more productive firms can afford the fixed costs of offshoring, and their number varies over time. The model also implies that the relocation of production offshore takes place one-way: Since the cost of effective labor is relatively lower in the South, only Northern firms have the incentive to relocate production offshore. All Southern firms produce domestically.⁹

The implications of the model are consistent with the empirical evidence provided by recent studies on the determinants of vertical production networks. For instance, Hanson, Mataloni, and Slaughter (2005) show that U.S. multinational firms import more interme-

⁸I define the cost of effective labor as the ratio between the real wage and aggregate productivity (w_t/Z_t in the North and w_t^*/Z_t^* in the South).

⁹I derive an asymmetric steady state in which differences in the regulation of firm entry in the country of origin are translated in differences in real effective wages across countries. In the model, I set firm entry costs to be higher in the South; in turn, since the more regulated economy attracts a smaller number of firms, labor demand and the cost of effective labor are lower in the South.

diate inputs when their foreign affiliates benefit from lower wages and lower trade costs in the host economy. Kurz (2006) shows that U.S. firms choosing to offshore are *ex-ante* larger and more productive than their domestic counterparts, as their higher idiosyncratic productivity levels allow them to cover the fixed costs of offshoring.

The key results of the paper are as follows. First, the model generates a procyclical pattern of offshoring that is consistent with the stylized facts from Mexico’s maquiladora industry. In particular, following an economic expansion in the parent country, the value added per offshoring firm (the intensive margin) spikes on impact. Domestic firm entry leads to a gradual appreciation of the terms of labor, which in turn generates a gradual increase in the number of offshoring firms over time (the extensive margin).¹⁰ Second, offshoring enhances the co-movement of output relative to the benchmark model with exports developed in Ghironi and Melitz (2005). As firm entry places upward pressure on the domestic effective wage and causes more firms to relocate production offshore, higher demand for domestic labor (due to firm entry) and sequentially higher demand for offshore labor (due to the relocation of production) enhance the co-movement of wages and aggregate incomes.¹¹ The result is consistent with the empirical regularity documented by Burstein, Kurz, and Tesar (2007) that countries with stronger offshoring-related trade links tend to exhibit higher correlations of manufacturing output. Third, offshoring narrows the price dispersion across countries, as it dampens the appreciation of the real exchange rate that follows an increase in aggregate productivity in the parent country (the Harrod-Balassa-

¹⁰The terms of labor is defined as the ratio between the Southern and Northern real cost of effective labor expressed in units of the same consumption basket, $TOL_t = \frac{Q_t w_t^*/Z_t^*}{w_t/Z_t}$, as in Ghironi and Melitz (2005). An increase in the cost of effective labor in the North would cause the terms of labor to appreciate (i.e. TOL decreases).

¹¹In contrast, in the traditional IRBC literature, a domestic increase in aggregate productivity leads to increased production at home but not offshore, such as in Backus, Kehoe, Kydland (1992).

Samuelson effect). This result is driven by several channels, including the upward pressure on the foreign wage, the decrease in size of the domestic non-traded sector, and the decline in import prices that occurs as offshoring crowds out the less productive foreign exporters. Fourth, offshoring enhances the procyclicality of investment and firm entry in the parent country relative to the benchmark model with exports only, as the lower-cost alternative of producing offshore increases the profitability of domestic firms. In turn, the employment loss caused by offshoring is partially offset by the employment gain generated by greater domestic firm entry.

This paper is related to a growing body of macroeconomic literature that focuses on endogenous firm entry and adjustments along the extensive margin of exports (but not of offshoring).¹² For example, Ghironi and Melitz (2005) study the export decision of firms in the presence of fixed exporting costs, in a framework with firm entry and firm heterogeneity. Alessandria and Choi (2007) analyze the extensive margin of exports in a model with sunk and continuation fixed costs that explains the "exporter hysteresis" behavior.¹³ Corsetti, Martin, and Pesenti (2007) examine the terms-of-trade implications of productivity improvements affecting the entry of firms and the production sector, in a model in which the extensive margin of exports is endogenous. And Mejean (2006) emphasizes the implications of endogenous firm entry in the tradable sector for the real exchange rate

¹²Recent empirical literature highlights the role of the extensive margin in international trade in the presence of fixed exporting costs: Baldwin and Harrigan (2007) show that the number of traded goods (the extensive margin) decreases with distance and increases with the size of the importing country. Besedes and Prusa (2006) find that the survival rate of exports for differentiated good varieties increases with the initial transaction size and also with the length of the relationship. Hummels and Klenow (2005) show that larger economies have larger exports, and that the extensive margin accounts for as much as 60 percent of this difference.

¹³"Exporter hysteresis" refers to the behavior of firms that continue to serve the foreign market even after a real exchange rate appreciation reduces their export competitiveness.

dynamics and the Harrod-Balassa-Samuelson effect.

The study of the macroeconomic implications of offshoring through vertical FDI is particularly relevant for pairs of countries and for economic areas that are separated by persistent differences in the cost of effective labor. For instance, offshoring through vertical FDI has been important for the U.S. multinational firms acting within the NAFTA region, and also within Central and South America: As much as 50 percent of the manufacturing sales of U.S. affiliates in Mexico (and 26 percent of the sales of U.S. affiliates in Latin America as a whole) were directed towards their U.S. parent firms in 2005 (as opposed to only 3 percent for the U.S. affiliates in Europe, and 5 percent for those in the Asia-Pacific region; BEA, 2007). A similar pattern exists between Western Europe and the new member countries of the European Union (Marin, 2006; Meyer, 2006).

The rest of this paper is organized as follows: Section 2 introduces a DSGE model of offshoring that allows for fluctuations in offshoring at both the extensive and the intensive margins; Section 3 defines the average productivity levels of the representative firms producing domestically and offshore; Section 4 discusses the model calibration; Section 5 presents the results, including the macroeconomic dynamics in the presence of aggregate productivity shocks, as well as a comparison between the empirical moments of offshoring to Mexico and their model counterparts; Section 6 concludes with a summary and proposed extensions of the model.

1.2 Model of Offshoring with Heterogeneous Firms

1.2.1 Model Setup: Markets and Production Strategies

This section summarizes the two-stage model of firm entry and offshore production, which I illustrate in Figure 1. In the first stage, an unbounded pool of potential entrant firms face a trade-off between the sunk entry cost (reflecting the cost of starting a business in the firms' country of origin), the expected stream of future monopolistic profits, and the probability of exit very period, as in Ghironi and Melitz (2005, henceforth GM2005). Only after paying the sunk entry cost, each firm is assigned an idiosyncratic labor productivity factor that is drawn independently from a common distribution over a support interval, and that the firm keeps for the entire duration of its life.

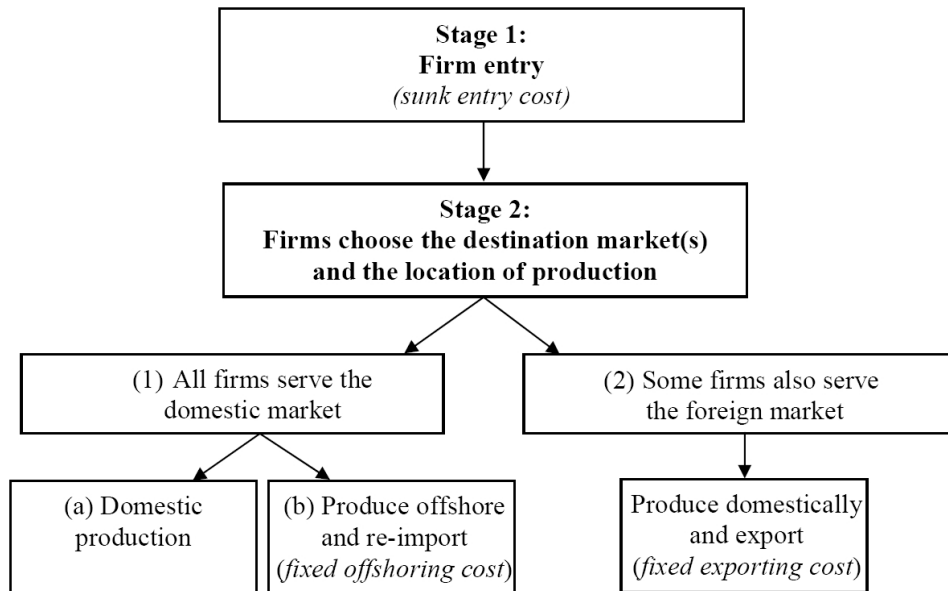


Figure 1. Destination markets and production strategies of firms

In the second stage, post-entry firms are monopolistically competitive and heterogeneous

in labor productivity. Every period after entry, firms choose the destination market(s) that they serve as well as the location of production, as follows: (1) Firms serving their domestic market can use either domestic or foreign inputs in production. The use of foreign labor involves the establishment of offshore production plants (offshoring through vertical FDI). It offers the advantage of a lower production cost, but is subject to a per-period fixed offshoring cost, and to an iceberg trade cost that affects the final goods shipped back to the country of origin for final consumption. (2) Some of the firms can also serve the foreign market. To this end, they use domestic labor as the only input in the production of final goods which they export subject to a per-period fixed exporting cost, as in GM2005. Thus, I nest the model of GM2005 (exports only, no offshoring) as a special case in my model with offshoring.¹⁴

Next I describe in detail the model with firm entry and offshore production.

1.2.2 Firms Serving the Domestic Market: Domestic vs. Offshore Production

This section outlines the mechanisms of domestic and offshore production for the Northern firms. It does not concern the Southern firms, as offshoring takes place one-way, from the Northern economy to the low-wage South.

In the North, a continuum of monopolistically-competitive firms produce final goods for

¹⁴I abstract from the possibility of offshoring through horizontal FDI: As an alternative to exports, firms serving the foreign market may produce abroad using the local labor of the country whose market they target, thus engaging in offshoring through horizontal FDI as in Contessi (2006). Production under horizontal FDI is motivated by improved access to the foreign market, and involves the simultaneous production of the same final good variety both at home (to be sold in the home market) and offshore (to be sold in the host market). In contrast to horizontal FDI, firms engaging in vertical FDI shift part of the production chain offshore in order to take advantage of the relatively lower cost of effective labor. They relocate downstream production activities offshore (e.g. manufacturing, assembly and packaging) while continuing to perform the upstream operations (e.g. research, marketing and sales) at home.

the domestic market. Firms are heterogeneous in productivity, with each firm producing a different variety of final goods. Since each firm produces one variety, the firm-specific labor productivity z also serves as an index for the existing varieties of final goods. Every period, firms producing for the domestic market can choose one of two possible locations of production:

(1) Domestic production: The Northern firm with idiosyncratic labor productivity z employs labor l_t to obtain an amount of final goods:

$$y_{D,t}(z) = Z_t z l_t, \tag{1.1}$$

where Z_t is the aggregate productivity of labor in the North and z is the firm-specific labor productivity;

(2) Offshore production: Alternatively, the firm with idiosyncratic labor productivity z may choose to relocate production offshore using Southern labor l_t^* as the only input in production:

$$y_{V,t}(z) = Z_t^* z l_t^*. \tag{1.2}$$

Thus, I assume that each offshoring firm becomes subject to the Southern aggregate labor productivity Z^* , but is able to carry its own idiosyncratic labor productivity z to the Southern economy.¹⁵ Given the demand for final good varieties produced domestically, $y_{D,t}(z) = \rho_{D,t}(z)^{-\theta} C_t$, and also the demand for varieties produced offshore by the vertically-

¹⁵Strategies 1.1 and 1.2 are extreme cases of a broader framework of offshoring, in which I allow for the offshoring firm with idiosyncratic labor productivity z to use a mix of Northern and Southern labor, l_t and l_t^* . Following the specification in Antras and Helpman (2004), the production of final good variety z is a

integrated firms, $y_{V,t}(z) = \rho_{V,t}(z)^{-\theta} C_t$,¹⁶ the monopolistically-competitive firms solve their profit-maximization problem:

$$\max_{\{\rho_{D,t}(z)\}} d_D(z) = \rho_{D,t}(z) y_{D,t}(z) - \frac{w_t}{Z_t} y_{D,t}(z), \quad (1.3)$$

$$\max_{\{\rho_{V,t}(z)\}} d_V(z) = \rho_{V,t}(z) y_{V,t}(z) - \tau \frac{w_t^* Q_t}{Z_t^* z} y_{V,t}(z) - f_V \frac{w_t^* Q_t}{Z_t^*}. \quad (1.4)$$

The cost of producing one unit of output either domestically or offshore varies not only with the cost of effective labor $\frac{w_t}{Z_t}$ and $\frac{w_t^* Q_t}{Z_t^*}$ across countries, but also with the level of idiosyncratic labor productivity z across firms.¹⁷ I define the real exchange rate $Q_t = \frac{P_t^* \varepsilon_t}{P_t}$ as the ratio between the price indexes in the South and North expressed in the same currency, where ε_t is the nominal exchange rate. In addition to the marginal cost, the Northern firms producing offshore incur a period-by-period fixed offshoring cost equal to f_V units of Southern effective labor, a cost that reflects the building and maintenance of the offshore production facility.¹⁸ They also face an iceberg trade cost ($\tau > 1$) associated with the

Cobb-Douglas function of domestic and foreign inputs:

$$y_{V,t}(z) = \left[\frac{Z_t z l_t}{\alpha} \right]^\alpha \left[\frac{Z_t^* z l_t^*}{1 - \alpha} \right]^{1 - \alpha}.$$

In this paper, I explore the implications of offshoring under two extreme scenarios: At one extreme, I set $\alpha = 1$ to shut down offshoring under vertical FDI, in which case firms use exclusively domestic inputs in production (in this case I revisit GM2005). At the other extreme, I set $\alpha = 0$ so that the offshoring firms use exclusively foreign inputs in the production of final goods. The smaller α , the larger the range of operations that the offshoring firms relocate abroad (e.g. manufacturing, assembly, packaging, customer service). For the two extreme cases, I use the l'Hôpital rule to obtain: $\lim_{\alpha \rightarrow 0} \left(\frac{1}{\alpha} \right)^\alpha =$

$$\lim_{\beta \rightarrow \infty} \beta^{1/\beta} = \lim_{\beta \rightarrow \infty} e^{(1/\beta) \ln \beta} = e^{\lim_{\beta \rightarrow \infty} \left(\frac{\ln \beta}{\beta} \right)} \text{ l'Hôpital} = \lim_{\beta \rightarrow \infty} (1/\beta) = e^0 = 1.$$

¹⁶I provide their derivation in the Appendix.

¹⁷Given the domestic and offshore real wages, w_t and w_t^* respectively, the marginal cost of producing one unit of variety z domestically is $\frac{w_t}{Z_t z}$, and the marginal cost of producing it offshore is $\frac{w_t^* Q_t}{Z_t^* z}$. The real wage $w_t = W_t/P_t$ in North is expressed in units of the domestic consumption basket; the offshore real wage $w_t^* = W_t^*/P_t^*$ is expressed in units of the consumption basket in South.

¹⁸The cost of f_V units of Southern effective labor is equivalent to $f_V w_t^*/Z_t^*$ units of the Southern consumption basket.

shipping of goods produced offshore back to the parent country: For every τ units produced offshore, only one unit reaches the Northern consumers, as the difference is lost due to costs associated with trade barriers, transportation, insurance, and differences in the legal systems, as discussed in Anderson and Wincoop (2004).

The profit-maximization problem under monopolistic competition implies the following equilibrium prices per unit of output produced domestically and offshore, respectively:¹⁹

$$\rho_{D,t}(z) = \frac{\theta}{\theta - 1} \frac{w_t}{Z_t z} \quad (1.5)$$

$$\rho_{V,t}(z) = \frac{\theta}{\theta - 1} \tau \frac{w_t^* Q_t}{Z_t^* z}. \quad (1.6)$$

The resulting profits from domestic and offshore production, both expressed in units of the Northern consumption basket C_t , are:²⁰

$$d_{D,t}(z) = \frac{1}{\theta} \rho_{D,t}(z)^{1-\theta} C_t, \quad (1.7)$$

$$d_{V,t}(z) = \frac{1}{\theta} \rho_{V,t}(z)^{1-\theta} C_t - f_V \frac{w_t^* Q_t}{Z_t^*}. \quad (1.8)$$

To summarize the above, the profits associated with domestic and offshore production depend on the cost of effective labor in the North and South, the fixed offshoring cost, the iceberg trade cost, as well as the firm-specific labor productivity. Firms producing offshore benefit from the relatively lower cost of effective labor, but their profits decline with the per-period fixed offshoring cost, and also with the iceberg trade cost. Thus, when deciding

¹⁹The derivations are provided in the Appendix.

²⁰Using the demand $y_D(z) = \rho_D(z)^{-\theta} C$ and the price $\rho_D(z) = \frac{\theta}{\theta-1} \frac{w}{Zz}$ for domestic production, the corresponding profit is $d_D(z) = \frac{1}{\theta} \rho_D(z) y_D(z)$. The profit from offshore production is analogous.

upon the location of production every period, the firm with productivity z compares the profit $d_{D,t}(z)$ it would obtain from domestic production with the profit $d_{V,t}(z)$ it would obtain from producing the same variety offshore.

The model implies that only the relatively more productive Northern firms find it profitable to locate production offshore every period. Despite the lower cost of effective labor in South relative to North, only firms with idiosyncratic productivity above a certain cutoff ($z > z_{V,t}$) obtain profits that are large enough to cover the fixed offshoring cost and the iceberg trade cost. This implication of the model is consistent with the empirical evidence provided by Kurz (2006) that firms choosing to produce offshore are *ex-ante* larger and more productive than their domestic counterparts, as the larger idiosyncratic productivity levels allow them to cover the fixed costs of offshoring.²¹

As a particular case, the firm with labor productivity equal to the cutoff $z_{V,t}$ is indifferent between producing domestically or offshore. After accounting for the fixed offshoring cost and the iceberg trade cost, the firm at the cutoff obtains equal profits from domestic and offshore production, a property which I use to solve for the endogenous productivity cutoff $z_{V,t}$ that governs the location decision of production:

$$z_{V,t} = \{z \mid d_{D,t}(z_{V,t}) = d_{V,t}(z_{V,t})\}. \quad (1.9)$$

²¹A useful implication of firm heterogeneity along the lines of Melitz (2003) is that the more productive firms have larger output and revenue. Given two firms with idyodyncratic productivity $z_2 > z_1$, the ratios of output and profits are $\frac{y(z_2)}{y(z_1)} = \left(\frac{z_2}{z_1}\right)^\theta > 1$, $\frac{r(z_2)}{r(z_1)} = \left(\frac{z_2}{z_1}\right)^{\theta-1} > 1$. Empirical studies show that firms using imported inputs in production not only are more productive, but also are larger and employ more workers (Kurz, 2006; Yasar and Morrison Paul, 2006).

Existence of the equilibrium productivity cutoff Next I show that the existence of the equilibrium productivity cutoff $z_{V,t}$ requires a cross-country asymmetry in the cost of effective labor, so that some of the Northern firms will always maintain an incentive to produce offshore.

I begin by re-writing the expressions for profits obtained from domestic and offshore production as $d_{D,t}(z) = B_t \left(\frac{w_t}{Z_t}\right)^{1-\theta} z^{\theta-1}$ and $d_{V,t}(z) = B_t \left(\tau \frac{w_t^* Q_t}{Z_t^*}\right)^{1-\theta} z^{\theta-1}$, respectively, where $B_t \equiv \frac{1}{\theta} \left(\frac{\theta}{1-\theta}\right)^{1-\theta} C_t$ is a measure of the market size in the North. In Figure 2, I plot the corresponding profits as functions of the idiosyncratic productivity parameter $z^{\theta-1}$ over the support interval $[z_{min}, \infty)$. The vertical intercepts represent the annualized value of the sunk entry cost for the case of domestic production ($-\Theta f_E \frac{w_t}{Z_t}$), and the annualized value of the sunk entry cost plus the period-by-period fixed cost for the case of offshore production ($-\Theta f_E \frac{w_t}{Z_t} - f_V \frac{w_t^* Q_t}{Z_t^*}$), where parameter $\Theta \equiv \frac{1-\beta(1-\delta)}{\beta(1-\delta)}$.

The existence of equilibrium productivity cutoff $z_{V,t}$ requires that the following condition holds every period: The profit function for offshoring must be steeper than that for domestic production, i.e. $\text{slope } \{d_{V,t}(z)\} > \text{slope } \{d_{D,t}(z)\}$. When the condition is met, offshoring generates greater profits than domestic production for the Northern firms with idiosyncratic productivity z along the upper range of the support interval. The slope inequality is equivalent to:

$$\tau \frac{w_t^* Q_t / Z_t^*}{w_t / Z_t} < 1, \quad (1.10)$$

which implies that the effective wage in the South must be sufficiently lower than that in the North, so that the difference covers the iceberg trade cost ($\tau > 1$) and thus provides an

incentive for some of the Northern firms to produce offshore every period.²²

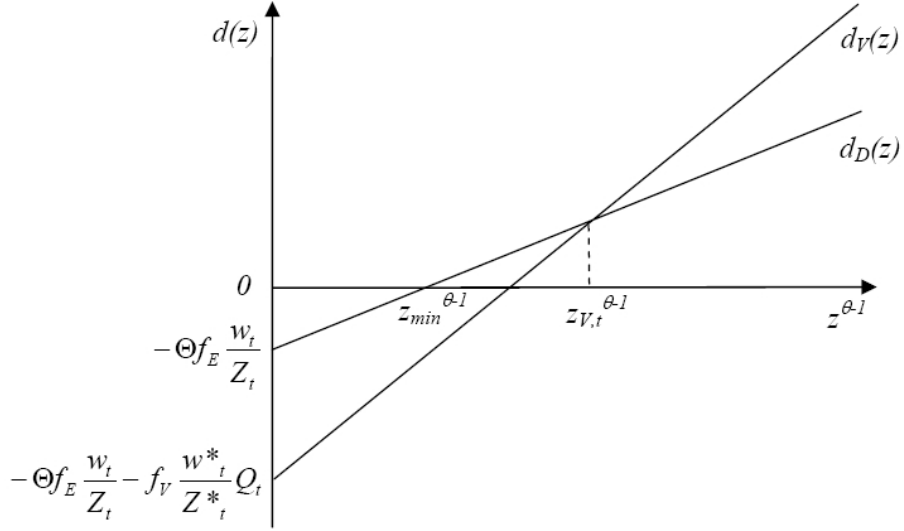


Figure 2. Existence of equilibrium productivity cutoff $z_{V,t}$.

1.2.3 Firms Serving the Foreign Market: Exports

In this section I describe the problem of the exporting firms originating in the North. The equations for the Southern firms are similar unless indicated otherwise. Variables for the Southern economy are marked with the (*) superscript.

Firms in each economy have the option to serve the foreign market through exports, as in GM2005. Thus, the Northern exporting firm with idiosyncratic productivity z uses an amount of domestic labor l_t in the production of its final good variety $y_{H,t}(z)$ exported the

²²See Appendix 9. A second condition, necessary to avoid the corner solution when all firms would produce offshore, is that the productivity cutoff must be larger than the lower bound of the support interval: $z_{V,t} > z_{min}$. This condition is equivalent to $d_{D,t}(z_{min}) < \Theta f_E \frac{w_t}{Z_t} + f_V \frac{w_t^* Q_t}{Z_t^*}$, which shows that the firm with idiosyncratic productivity equal to the lower-bound level z_{min} would obtain zero profits from domestic production and negative profits from offshore production.

Southern market:²³

$$y_{H,t}(z) = Z_t z l_t. \quad (1.11)$$

Serving the foreign market involves a period-by-period fixed exporting cost equal to f_H units of Northern effective labor as well as the iceberg trade cost τ^* . The profit maximization problem of the Northern exporting firms generates the following price and profit functions:

$$\rho_{H,t}(z) = \frac{\theta}{\theta - 1} \tau^* \frac{w_t Q_t^{-1}}{Z_t z}, \quad (1.12)$$

$$d_{H,t}(z) = \frac{1}{\theta} \rho_{H,t}(z)^{1-\theta} C_t^* Q_t - f_H \frac{w_t}{Z_t}. \quad (1.13)$$

The model implies that every period t , the Northern firms with idiosyncratic labor productivity above a certain cutoff ($z > z_{H,t}$) find it profitable to export to the Southern market at the same time with serving their domestic market (North). They obtain profits that are large enough to cover both the fixed cost and the iceberg trade cost of exporting. As in GM2005, the firm with the idiosyncratic labor productivity equal to the cutoff obtains zero

²³I view exporting as a special case within a broader framework, in which I allow for firms to serve the foreign market by using a mix of domestic and foreign inputs in production. In this framework, production is described by the following Cobb-Douglas specification:

$$y_{H,t}(z) = \left[\frac{Z_t z l_t}{\eta} \right]^\eta \left[\frac{Z_t^* z l_t^*}{1 - \eta} \right]^{1-\eta},$$

where a larger η accounts for a smaller content of Southern inputs used in the production of final goods sold for consumption in the Southern market. In this paper I nest the special case with endogenous exports in GM2005 under the calibration $\eta = 1$. Alternatively, I would nest the case in which firms serving the Southern market produce exclusively through their foreign affiliates (as in Contessi, 2006) by setting $\eta = 0$. In the latter case, production in the South through horizontal FDI allows firms to avoid the trade cost τ^* by using local inputs. Using the l'Hôpital rule, $\lim_{\eta \rightarrow 0} \left(\frac{1}{\eta} \right)^\eta = \lim_{\beta \rightarrow \infty} \beta^{1/\beta} = \lim_{\beta \rightarrow \infty} e^{(1/\beta) \ln \beta} = e^{\lim_{\beta \rightarrow \infty} \left(\frac{\ln \beta}{\beta} \right)}$ *l'Hôpital*
 $e^{\lim_{\beta \rightarrow \infty} (1/\beta)} = e^0 = 1$. The corresponding price and profit functions are $\rho_{H,t}(z) = \frac{\theta}{\theta - 1} \left(\tau^* \frac{w_t Q_t^{-1}}{Z_t z} \right)^\eta \left(\frac{w_t^*}{Z_t^* z} \right)^{1-\eta}$
and $d_{H,t}(z) = \frac{1}{\theta} \rho_{H,t}(z)^{1-\theta} C_t^* Q_t - f_H \left(\frac{w_t}{Z_t} \right)^\eta \left(\frac{w_t^* Q_t}{Z_t^*} \right)^{1-\eta}$.

profits from exporting. Thus, the time-variant productivity cutoff $z_{H,t}$ is obtained as:

$$z_{H,t} = \inf \{z \mid d_{H,t}(z_{V,t}) > 0\}. \quad (1.14)$$

1.2.4 Households

Financial autarky Households in each country maximize the expected lifetime utility (as a function of consumption) and provide labor inelastically:

$$\max_{\{B_{t+1}, x_{t+1}\}} \left[E_t \sum_{s=t}^{\infty} \beta^{s-t} \frac{C_s^{1-\gamma}}{1-\gamma} \right], \quad (1.15)$$

subject to the budget constraint:

$$(\tilde{v}_t + \tilde{d}_t)N_t x_t + (1 + r_t)B_t + w_t L \geq \tilde{v}_t (N_t + N_{E,t}) x_{t+1} + B_{t+1} + C_t, \quad (1.16)$$

where $\beta \in (0, 1)$ is the subjective discount factor, C_t is the consumption basket, and $\gamma > 0$ is the inverse of the inter-temporal elasticity of substitution.

The representative Northern household starts every period t with mutual fund share holdings x_t (whose market value is $\tilde{v}_t N_t$) and real bond holdings B_t . It receives dividend income $\tilde{d}_t N_t$ on the mutual fund stocks (equal to the profit of the average firm times the number of firms) in proportion with its stock holdings x_t . It also receives interest $r_t B_t$ on bond holdings, and labor income equal to the real wage w_t for the amount of labor $L = 1$ that it supplies inelastically. The Northern household purchases two types of assets every period. First, it purchases x_{t+1} shares in a mutual fund of Northern firms that includes: (i) N_t firms already producing at time t , either domestically or offshore, and (ii) $N_{E,t}$ new

firms that enter the domestic market in period t . Each share is worth its market value \tilde{v}_t , equal to the net present value of the expected stream of future profits of the average firm. Second, the household buys the risk-free bond B_{t+1} denominated in units of the Northern consumption basket. (Bond holdings play a role in the extended model with international trade in bonds, which I present in the Appendix.)²⁴

In addition, households purchase the consumption basket C_t , which includes varieties of final goods produced by Northern firms ($\omega \in \Omega_t^{NN}$) either domestically or offshore; it also includes the imports of final good varieties produced by the Southern firms ($\omega \in \Omega_t^{SN}$):

$$C_t = \left[\underbrace{\int_{z_{\min}}^{z_{V,t}} y_{D,t}(\omega)^{\frac{\theta-1}{\theta}} d\omega}_{\text{Domestic production}} + \underbrace{\int_{z_{V,t}}^{\infty} y_{V,t}(\omega)^{\frac{\theta-1}{\theta}} d\omega}_{\text{Offshore production}} + \underbrace{\int_{z_{H,t}^*}^{\infty} y_{H,t}^*(\omega)^{\frac{\theta-1}{\theta}} d\omega}_{\Omega_t^{SN}} \right]^{\frac{\theta}{\theta-1}}, \quad (1.17)$$

where $\theta > 1$ is the symmetric elasticity of substitution across final good varieties. I use the home consumption basket C_t as the numeraire good, and define the real price of variety z in units of the Northern consumption basket as $\rho_t(z) = p_t(z)/P_t$. Thus, the the consumption-based price index in the North is:²⁵

$$1 = \left[\int \rho_t(\omega)^{1-\theta} d\omega \right]^{\frac{1}{1-\theta}}, \quad \omega \in \Omega_t^{NN} \cup \Omega_t^{SN}. \quad (1.18)$$

²⁴In the model with complete financial autarky (i.e. stocks in the mutual fund and bonds are not traded across countries), the equilibrium conditions for stock and bond holdings are $x_t = x_{t+1} = 1$ and $B_t = B_{t+1} = 0$.

²⁵If $p_t(z)$ denotes the price of each variety z , the price index of the home consumption basket is $P_t = \left[\int p_t(\omega)^{1-\theta} d\omega \right]^{\frac{1}{1-\theta}}$ for $\omega \in \Omega_t^{NN} \cup \Omega_t^{SN}$. The demand for each variety of final goods z is $y_t(z) = (p_t(z)/P_t)^{-\theta} C_t$.

The first-order conditions generate the Euler equations for bonds and stocks:

$$C_t^{-\gamma} = \beta (1 + r_{t+1}) E_t [C_{t+1}^{-\gamma}], \quad (1.19)$$

$$\tilde{v}_t = \beta(1 - \delta) E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (\tilde{d}_{t+1} + \tilde{v}_{t+1}) \right]. \quad (1.20)$$

1.2.5 Firm Entry and Exit

Following GM2005, firm entry takes place every period. In the North, firm entry requires a sunk entry cost equal to f_E units of Northern effective labor, which reflects the cost of starting a business in the firms' country of origin.²⁶ Potential entrants become aware of their idiosyncratic labor productivity z only after entering the market. After paying the sunk entry cost, each firm is randomly assigned an idiosyncratic labor productivity z which is drawn independently from a common distribution $G(z)$ with support over the interval $[z_{min}, \infty)$, and which the firm keeps for the entire duration of its life.

The potential entrant firms are forward looking and correctly anticipate their expected post-entry value \tilde{v}_t , which is given by the expected stream of future profits \tilde{d}_t and by the exogenous probability δ with which they receive an exit-inducing shock every period. The forward iteration of the Euler equation for stocks (1.20) generates the expression for the expected post-entry value of potential entrants:

$$\tilde{v}_t = E_t \left\{ \sum_{s=t+1}^{\infty} [\beta(1 - \delta)]^{s-t} \left(\frac{C_s}{C_t} \right)^{-\gamma} \tilde{d}_s \right\}. \quad (1.21)$$

In equilibrium, firm entry takes place until the value of the average firm \tilde{v}_t equals the sunk

²⁶Or $f_E w_t / Z_t$ units of the consumption basket in the North.

entry cost $f_E \frac{w_t}{Z_t}$, both expressed in units of the Northern consumption basket:

$$\tilde{v}_t = f_E \frac{w_t}{Z_t}. \quad (1.22)$$

The $N_{E,t}$ firms entering at time t do not produce until period $t + 1$. Irrespective of their idiosyncratic productivity, all firms - including the new entrants - are subject to a random exit shock that occurs with probability δ at the end of every period after production has taken place. Thus, the law of motion for the number of producing firms is:

$$N_{t+1} = (1 - \delta)(N_t + N_{E,t}), \quad (1.23)$$

where $N_t = N_{t,D} + N_{t,V}$ consists of firms producing either domestically or offshore every period.

1.3 Solving the Model with Firm Heterogeneity

A necessary step in solving the model with firm heterogeneity is to derive analytical solutions for the average productivity, prices and profits of the representative Northern firms that produce domestically and offshore. This section also provides the expressions for aggregate accounting and the balance of international payments that close the model with offshoring.

1.3.1 Average Firm Productivity Levels

Firms serving the domestic market I define two average labor productivity levels:

(1) the average productivity $\tilde{z}_{D,t}$ of the Northern firms producing domestically, and (2)

the average productivity $\tilde{z}_{V,t}$ of the Northern firms producing offshore. I illustrate them in Figure 3, in which I plot the density of the firm-specific labor productivity levels z over the support interval $[z_{min}, \infty)$.

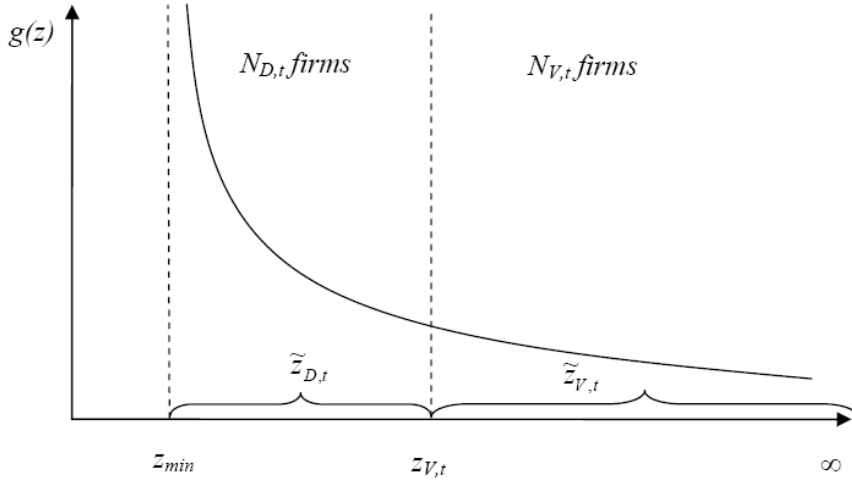


Figure 3. Average labor productivities for firms serving the domestic market through domestic (\tilde{z}_D, t) and offshore (\tilde{z}_V, t) production

Every period t , there are $N_{D,t}$ of the relatively less productive Northern firms ($z < z_{V,t}$) that choose to produce domestically; their average productivity is $\tilde{z}_{D,t}$. The remaining $N_{V,t}$ are the relatively more productive Northern firms ($z > z_{V,t}$) that choose to produce offshore;²⁷ their average productivity is $\tilde{z}_{V,t}$.²⁸ Since the firm-specific labor productivities z are random draws from a common distribution $G(z)$ with density $g(z)$, I write the average

²⁷The total number of Northern firms is $N_t = N_{V,t} + N_{D,t}$.

²⁸The difference between $\tilde{z}_{V,t}$ and $z_{V,t}$ is that the former is the average productivity of offshoring firms, whereas the latter is the cutoff productivity above which firms produce offshore.

idiosyncratic productivities of the Northern firms producing domestically and offshore as:

$$\tilde{z}_{D,t} = \left[\frac{1}{G(z_{V,t})} \int_{z_{\min}}^{z_{V,t}} z^{\theta-1} g(z) dz \right]^{\frac{1}{\theta-1}} \quad \text{and} \quad \tilde{z}_{V,t} = \left[\frac{1}{1 - G(z_{V,t})} \int_{z_{V,t}}^{\infty} z^{\theta-1} g(z) dz \right]^{\frac{1}{\theta-1}}. \quad (1.24)$$

Pareto-distributed firm productivity Following Melitz (2003) and GM2005, I assume that the firm-specific labor productivity draws z are Pareto-distributed, with p.d.f. $g(z) = kz_{\min}/z^{k+1}$ and c.d.f. $G(z) = 1 - (z_{\min}/z)^k$ over the support interval $[z_{\min}, \infty)$. Using this assumption, I derive analytical solutions for the average productivities of the two representative Northern firms producing domestically and offshore as functions of the time-variant productivity cutoff $z_{V,t}$:²⁹

$$\tilde{z}_{D,t} = \nu z_{\min} z_{V,t} \left[\frac{z_{V,t}^{k-(\theta-1)} - z_{\min}^{k-(\theta-1)}}{z_{V,t}^k - z_{\min}^k} \right]^{\frac{1}{\theta-1}} \quad \text{and} \quad \tilde{z}_{V,t} = \nu z_{V,t}, \quad (1.25)$$

where the productivity cutoff³⁰ is $z_{V,t} = z_{\min} (N_t/N_{V,t})^{(1/k)}$, and the parameters are $\nu \equiv \left[\frac{k}{k-(\theta-1)} \right]^{\frac{1}{\theta-1}}$ and $k > \theta - 1$.³¹ Since offshoring takes place one-way, from North to South, the Southern firms serve their domestic market exclusively through domestic production, and have a constant average productivity $\tilde{z}_D^* = \nu z_{\min}^*$.

²⁹I provide their derivation in the Appendix.

³⁰Parameter k reflects the dispersion of the productivity draws: A relatively larger k implies a smaller dispersion and a higher concentration of productivities z towards the lower productivity bound z_{\min} . Also, the condition $k > \theta - 1$ ensures that the variance of firm size is finite, given the average productivities of the firms producing domestically and offshore.

³¹The shares of Northern firms producing domestically and offshore, respectively, are $N_{D,t}/N_t = G(z_{V,t})$ and $N_{V,t}/N_t = 1 - G(z_{V,t})$, where the total number of Northern firms in every period is $N_t = N_{D,t} + N_{V,t}$. I use the functional form for the Pareto c.d.f. in order to derive the productivity cutoff as $z_{V,t} = z_{\min} (N_t/N_{V,t})^{(1/k)}$.

Exporting firms Under the assumption of Pareto-distributed productivity draws, I use the average productivity levels of the exporting firms originating in each economy as defined in GM2005:

$$\tilde{z}_{H,t} = \nu z_{\min} \left(\frac{N_t}{N_{H,t}} \right)^{1/k} \quad \text{and} \quad \tilde{z}_{H,t}^* = \nu z_{\min}^* \left(\frac{N_{D,t}^*}{N_{H,t}^*} \right)^{1/k}. \quad (1.26)$$

1.3.2 Average Prices and Profits

After deriving the average productivities, I re-write the model in terms of *three representative Northern firms*: one producing domestically, another producing offshore (each serving the Northern market), and a third firm producing domestically and exporting to the Southern market. Since the Southern firms do not produce offshore (due to the wage asymmetry across countries), there are only *two representative Southern firms*: one producing domestically for the local market, and the other exporting to the North.

Table 1. Average prices and profits

Production	Destination	Prices	Profits
Domestic	Domestic	$\tilde{\rho}_{D,t} = \frac{\theta}{\theta-1} \frac{w_t}{Z_t \tilde{z}_{D,t}}$	$\tilde{d}_{D,t} = \frac{1}{\theta} (\tilde{\rho}_{D,t})^{1-\theta} C_t$
		$\tilde{\rho}_{D,t}^* = \frac{\theta}{\theta-1} \frac{w_t^*}{Z_t^* \tilde{z}_{D,t}^*}$	$\tilde{d}_{D,t}^* = \frac{1}{\theta} (\tilde{\rho}_{D,t}^*)^{1-\theta} C_t^*$
Offshore	Domestic	$\tilde{\rho}_{V,t} = \frac{\theta}{\theta-1} \tau \frac{w_t^* Q_t}{Z_t^* \tilde{z}_{V,t}}$	$\tilde{d}_{V,t} = \frac{1}{\theta} (\tilde{\rho}_{V,t})^{1-\theta} C_t - f_V \frac{w_t^* Q_t}{Z_t^*}$
Domestic	Export	$\tilde{\rho}_{H,t} = \frac{\theta}{\theta-1} \tau^* \frac{w_t Q_t^{-1}}{Z_t \tilde{z}_{H,t}}$	$\tilde{d}_{H,t} = \frac{1}{\theta} (\tilde{\rho}_{H,t})^{1-\theta} C_t^* Q_t - f_H \frac{w_t}{Z_t}$
		$\tilde{\rho}_{H,t}^* = \frac{\theta}{\theta-1} \tau^* \frac{w_t^* Q_t}{Z_t^* \tilde{z}_{H,t}^*}$	$\tilde{d}_{H,t}^* = \frac{1}{\theta} (\tilde{\rho}_{H,t}^*)^{1-\theta} C_t Q_t^{-1} - f_H^* \frac{w_t^*}{Z_t^*}$

I use the average firm productivities defined above to write the prices and profits asso-

ciated with each representative firm, as shown in Table 1.

Endogenous productivity cutoff for offshoring Using the Pareto assumption and the property that the Northern firm at the productivity cutoff $z_{V,t}$ is indifferent about the location of production, I write the link between the profits of the two representative firms producing domestically and offshore for the Northern market as:³²

$$\tilde{d}_{V,t} = \frac{k}{k - (\theta - 1)} \left(\frac{z_{V,t}}{\tilde{z}_{D,t}} \right)^{\theta-1} \tilde{d}_{D,t} + \frac{\theta - 1}{k - (\theta - 1)} f_V \left(\frac{w_t}{Z_t} \right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*} \right)^{1-\alpha}. \quad (1.27)$$

The productivity cutoff for exports is also endogenous, as in GM2005. Using the property that the firm at the productivity cutoff $z_{H,t}$ obtains zero profits from exporting, the average profits from exports are:

$$\tilde{d}_{H,t} = \frac{\theta - 1}{k - (\theta - 1)} f_H \frac{w_t}{Z_t}, \text{ and } \tilde{d}_{H,t}^* = \frac{\theta - 1}{k - (\theta - 1)} f_H^* \frac{w_t^*}{Z_t^*}. \quad (1.28)$$

Endogenous productivity cutoff for offshoring The consumption price index in the Northern economy is an expression of the average prices of goods produced domestically and offshore by the Northern firms, as well as of the average price of goods imported from the South:

$$1 = N_{D,t} (\tilde{\rho}_{D,t})^{1-\theta} + N_{V,t} (\tilde{\rho}_{V,t})^{1-\theta} + N_{H,t}^* (\tilde{\rho}_{H,t}^*)^{1-\theta}. \quad (1.29)$$

Due to the relative wage asymmetry, there is no representative Southern firm producing offshore. The consumption price index in the South includes only the average price of goods

³²See the Appendix for the derivation.

produced domestically by Southern firms, and that of goods imported from the North:

$$1 = N_{D,t}^* (\tilde{\rho}_{D,t}^*)^{1-\theta} + N_{H,t} (\tilde{\rho}_{H,t})^{1-\theta}. \quad (1.30)$$

Total profits The total profits of the Northern firms include the average profits from domestic production, from offshore production, and from exporting:

$$N_t \tilde{d}_t = N_{D,t} \tilde{d}_{D,t} + N_{V,t} \tilde{d}_{V,t} + N_{H,t} \tilde{d}_{H,t}. \quad (1.31)$$

The total profits of the Southern firms combine the profits from domestic production and from exports:

$$N_{D,t}^* \tilde{d}_t = N_{D,t}^* \tilde{d}_{D,t} + N_{H,t}^* \tilde{d}_{H,t}^*. \quad (1.32)$$

1.3.3 Aggregate Accounting and the Balance of International Payments

I use value added as a measure of aggregate income in order to avoid the double-counting of offshore production conducted by the Northern firms in the South. Offshore production is measured as the wage bill of Southern workers, and belongs to the aggregate income of the Southern economy. Thus, aggregate income is the sum of the wage bill and the amount of stock dividends that households in each economy obtain every period:

$$Y_t = w_t + N_t \tilde{d}_t \quad \text{and} \quad Y_t^* = w_t^* + N_{D,t}^* \tilde{d}_t^*. \quad (1.33)$$

Under financial autarky in the markets for both bonds and stocks (i.e. $B_{t+1} = B_t = 0$ and $x_{t+1} = x_t = 1$ in equilibrium), aggregate accounting implies that households spend

their income from labor and stock holdings on consumption and investment in new firms:

$$C_t + N_{E,t}\tilde{v}_t = Y_t \quad \text{and} \quad C_t^* + N_{E,t}^*\tilde{v}_t^* = Y_t^*. \quad (1.34)$$

Finally, the real exchange rate Q_t is determined by the balanced current account condition for the Northern economy, which reflects the corresponding balance for the South:

$$CA_t^{Autarky} = \underbrace{N_{H,t}(\tilde{\rho}_{H,t})^{1-\theta} C_t^* Q_t}_{\text{Exports}} + \underbrace{N_{V,t}\tilde{d}_{V,t}}_{\text{Repatriated profits}} - \underbrace{N_{V,t}(\tilde{\rho}_{V,t})^{1-\theta} C_t}_{\text{Offshore value added}} - \underbrace{N_{H,t}^*(\tilde{\rho}_{H,t}^*)^{1-\theta} C_t}_{\text{Imports from Southern firms}}$$

Under financial autarky, the balanced current account condition ($CA_t^{Autarky} = 0$) implies that the sum of (a) exports by the Northern firms to the South and (b) repatriated profits of offshore affiliates must equal the sum of (c) the value of imports from offshore affiliates and (d) imports of final good varieties produced by the Southern firms.

1.3.4 Model Summary

As shown in Appendix A.1, the baseline model with financial autarky for the Northern economy can be summarized by 16 equations in 16 endogenous variables: N_t , $N_{D,t}$, $N_{V,t}$, $N_{H,t}$, $N_{E,t}$, \tilde{d}_t , $\tilde{d}_{D,t}$, $\tilde{d}_{V,t}$, $\tilde{d}_{H,t}$, $\tilde{z}_{D,t}$, $\tilde{z}_{V,t}$, $\tilde{z}_{H,t}$, \tilde{v}_t , r_t , w_t and C_t . As the Southern firms do not offshore to the high-wage North, the Southern economy is described by only 11 equations in 11 endogenous variables: There are no Southern counterparts for N_t , $N_{V,t}$, $\tilde{d}_{V,t}$, $\tilde{z}_{D,t}$ and $\tilde{z}_{V,t}$. In particular, the average labor productivity of the representative Southern firm producing for the domestic market (\tilde{z}_D^*) is constant over time. Variables $N_{D,t}$, r_t , N_t^* and r_t^* are predetermined.

1.4 Calibration

I use a standard quarterly calibration by setting the subjective rate of time discount $\beta = 0.99$ to match an average annualized interest rate of 4 percent. The coefficient of relative risk aversion is $\gamma = 2$. Following GM2005, I set the intra-temporal elasticity of substitution at $\theta = 3.8$, a value which corresponds to the U.S. plant and macro trade data. Although the resulting markup of 35.71 percent over the marginal cost might appear too large compared to the standard macroeconomic literature, its magnitude must be considered in the context of the sunk entry cost that places a wedge between the firms' marginal and average cost. I also calibrate the probability of firm exit $\delta = 0.025$ to match the annual 10 percent job destruction in the U.S.

As summarized in Table 2, I calibrate the fixed costs of offshoring (f_V) and exporting (f_H and f_H^*) as well as the Pareto distribution parameter (k) so that the model matches the importance of offshoring and trade for the Mexican economy, as illustrated by four empirical moments: (1) Maquiladora's value added represents approximately 20 percent of Mexico's manufacturing GDP (INEGI, 2008), as compared to 25 percent in the model; (2) Maquiladora's exports represent approximately half of Mexico's total exports (Bergin, Feenstra, and Hanson, 2008), as compared to 60 percent in the model; (3) Employment in the maquiladora sector accounts for approximately 25 percent of Mexico's total manufacturing employment (Bergin, Feenstra, and Hanson, 2008), as compared to 22 percent in the model; (4) Total imports represent the equivalent of 33 percent of Mexico's GDP (INEGI, 2008), as compared to 32 percent in the model. To this end, I set $f_V = 0.0057$ (the fixed cost of offshoring for Northern firms), $f_H = 0.032$ and $f_H^* = 0.018$ (the fixed costs of exporting

for Northern and Southern firms, respectively), as well as $k = 4.2$ (the Pareto distribution coefficient).³³ Without loss of generality, I set the lower bound of the support interval for firm-specific productivities in the North and the South at $z_{min} = z_{min}^* = 1$.

In order to derive an asymmetric steady state in which the cost of effective labor is relatively lower in the South, I set the sunk entry cost - which reflects the regulation of starting a business in the firm's country of origin - to be larger in the South ($f_E^* = 4f_E$, while setting $f_E = 1$ without loss of generality).³⁴ In turn, the relatively lower number of firms in steady state generates a lower labor demand and wage in the South. The calibration reflects the considerable variation in the cost of starting a business across countries: the monetary cost is 3.3 times higher in Mexico than in the U.S. or Canada; it is 6.2 times higher in Hungary than in the U.K. (World Bank, 2007; see Appendix 5). The asymmetric sunk entry costs, along with the trade iceberg cost ($\tau = 1.3$) and the values for f_V , f_H and f_H^* reported above, generate a steady state value for the terms of labor that is less than one ($TOL = 0.76$). Thus, the steady state cost of effective labor in the South, defined as the real wage divided by the aggregate productivity level, is 76 percent of the corresponding value in the North. The calibration provides an incentive for the Northern firms to produce

³³In the model with exports only, I set $f_H = 0.0260$ and $f_H^* = 0.0226$ so that the fraction of Northern exporting firms (10 percent) and that of Southern exporting firms (63 percent) match the corresponding steady state values in the model with offshoring.

³⁴The asymmetric sunk entry cost is one method that generates different effective wages across countries. The same result would be achieved with at least two other modeling devices: (1) Introduce a cross-country asymmetry in the size of firms (rather than in their number) through the price elasticity of demand. With identical sunk entry costs and equal average labor productivity levels in the two economies, firms in the economy with the lower price elasticity of demand charge relatively higher markups and produce relatively less output; in turn, the lower labor demand generates lower wages. (2) Another way to generate different firm sizes across countries, similar to the one I use in this paper, would be to allow for multi-product firms and sunk costs of creating new product varieties. While keeping the sunk firm entry costs equal across countries, there will be fewer varieties per firm and lower demand for labor in the economy with the higher sunk cost of creating a new variety.

offshore in steady state.

Table 2. Baseline model with offshoring: calibration

$f_E = 1$	Sunk firm entry cost, North	$k = 4.2$	Pareto distribution coefficient
$f_E^* = 4f_E$	Sunk firm entry cost, South	$\beta = 0.99$	Standard quarterly calibration
$f_V = 0.0057$	Fixed cost of offshoring	$\gamma = 2$	CRRA coefficient
$f_H = 0.0320$	Fixed cost of exporting, North	$\delta = 0.025$	Probability of firm exit
$f_H^* = 0.0180$	Fixed cost of exporting, South	$\theta = 3.8$	Elasticity of substitution

The resulting steady-state fraction of the Northern firms that use inputs imported from their offshore affiliates (N_V/N) is 1.4 percent; the fraction of exporting firms (N_H/N) is 10.1 percent.³⁵ Since I model offshoring in an asymmetric two-country framework that abstracts from exchanges between U.S. firms and the rest of the world (other than Mexico), the steady state values reported above are less than their empirical counterparts. In the data, approximately 14 percent of the U.S. firms (other than domestic wholesalers) used imports from both Mexico and the rest of the world in 1997 (Bernard, Jensen, Redding and Schott, 2007),³⁶ out of which intra-firm imports (as opposed to arm’s length transactions) represented half of the total (Bardhan and Jafee, 2004). Approximately 21 percent of the U.S. manufacturing plants were exporters in 1992 (Bernard, Eaton, Jensen and Kortum, 2003).

The calibration also implies that the steady-state share of Northern expenditure on the varieties produced by Northern firms domestically (66.0 percent) - firms which are relatively

³⁵In the Southern economy, the ratio of exporting firms in the total is 63 percent.

³⁶The value would understate the fraction of *plants* that use imported inputs if the importing *firms* tend to operate multiple plants manufacturing multiple product varieties.

less productive than the average - is less than their fraction in the total number of varieties available in the North (89.2 percent). In contrast, since the offshore varieties are produced by the relatively more productive Northern firms, their market share (21.2 percent) is more than their fraction in the total number of varieties available in the North (1.2 percent).³⁷

1.5 Results

1.5.1 Offshoring Dynamics

Under financial autarky, I log-linearize the model with offshore production around the steady state and compute the impulse responses to a transitory 1 percent increase in aggregate productivity in the North. I assume that productivity is described by the univariate process $\log Z_{t+1} = \rho \log Z_t + u_t$, with the persistence parameter $\rho = 0.9$.

Offshoring at the intensive margin Figure 4 shows the impulse responses of the model with offshoring (solid line), and contrasts them with the impulse responses of the benchmark model with endogenous exports and no offshoring as in GM2005 (dotted line). For each variable, the horizontal axis illustrates quarters after the initial shock, and the vertical axis shows the percent deviations from the original steady state in each quarter.

On impact, the 1 percent increase in aggregate labor productivity in the North generates an equal increase in the real wage w_t . The increased demand for the final good varieties already produced offshore causes a sudden increase in offshoring along its intensive margin.

As a result, the real wage in the South (w_t^*) and the terms of labor ($TOL_t = \frac{Q_t w_t^* / Z_t^*}{w_t / Z_t}$)

³⁷The market share of Southern varieties - produced by Southern firms that are relatively less productive than the Northern exporters - is 61.66 percent in the South. This is less than their fraction in the total number of varieties available in the South (62.77 percent).

spike upward on impact: Since the increase in aggregate labor productivity in the North is not replicated in the South, on impact there is excess demand for the Southern units of effective labor. Therefore, the number of Northern firms that produce offshore ($N_{V,t}$) declines on impact due to: (1) the increase in the cost of producing offshore, and (2) the increase in the fixed cost of relocation, both of which are sensitive to the cost of effective labor in the South.

Offshoring at the extensive margin Over the business cycle, as aggregate labor productivity in the North persists above the initial steady state, the larger market size encourages firm entry, which causes the number of Northern firms (N_t) to increase gradually over time (Figure 4). The rising number of incumbent firms causes an increase in labor demand in the North, and thus leads to a gradual appreciation of the cost of effective labor in the North relative to that in the South in the medium run (as shown by the decline of TOL_t below the initial steady state). Following the appreciation of the terms of labor, more of the Northern firms have an incentive to relocate production to the South. Hence, following the initial drop, the number of Northern firms that relocate production to the South ($N_{V,t}$) rises above the original steady state 4 quarters after the shock (i.e. offshoring increases along its extensive margin).

The initial upward spike in the Southern real wage, caused by the increased demand for final good varieties that were already produced offshore when the shock occurred, is followed by a hump-shaped increase in the Southern wage which occurs as more Northern firms relocate production offshore over the business cycle. Thus, the gradual increase in offshoring along its extensive margin places additional upward pressure on the Southern

wage and causes the terms of labor to appreciate by less (TOL to decrease by less) in the medium run relative to the benchmark model with exports only. As a result, the increase in labor demand in the North, caused by firm entry, and subsequently the increase in labor demand in the South, caused by offshoring, enhance the cross-country co-movement of wages and aggregate incomes relative to the benchmark model with exports only.

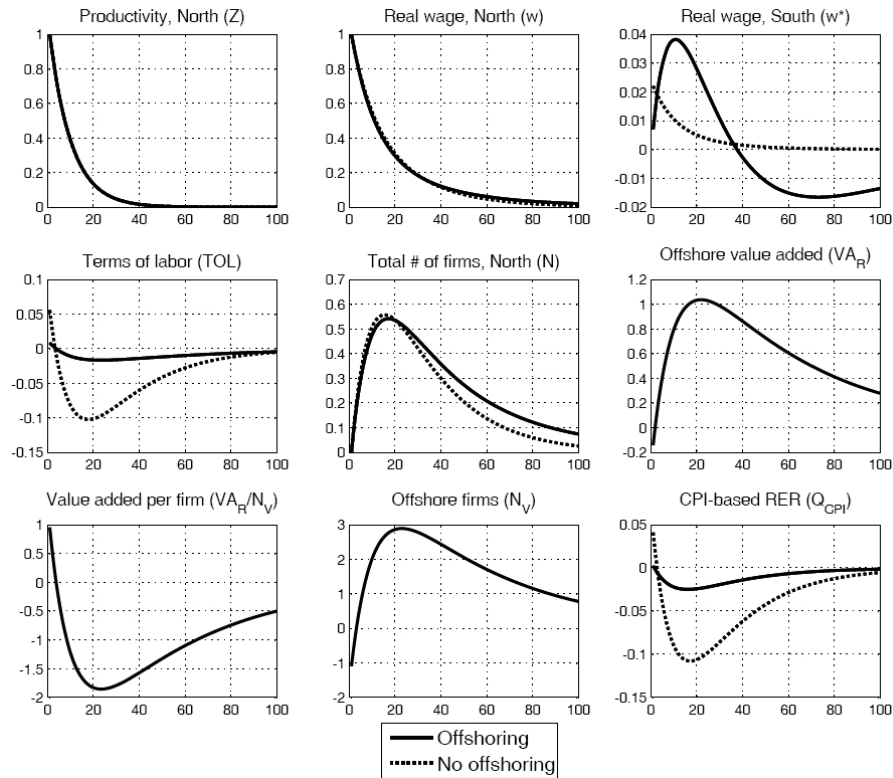


Figure 4. Endogenous offshoring (continuous line) vs. exports only (dotted line), impulse responses to a transitory 1 percent increase in aggregate productivity in the North

1.5.2 Real Exchange Rate Dynamics

Average prices and product variety In this section I analyze the model's predictions for the dynamics of relative prices in response to aggregate shocks. Due to the existence

of endogenous product variety in the model, I use the consumer price index (CPI)-based real exchange rate $\widetilde{Q}_t = \varepsilon_t \widetilde{P}_t^* / \widetilde{P}_t$ as the theoretical counterpart to the empirical real exchange rate, since the average prices \widetilde{P}_t and \widetilde{P}_t^* best represent the corresponding empirical CPI levels, as discussed in Broda and Weinstein (2003) and GM2005. To this end, I break down the welfare-based price indexes P_t and P_t^* into (a) components reflecting average prices (\widetilde{P}_t and \widetilde{P}_t^*) and (b) components reflecting product variety:³⁸

$$P_t = (N_{D,t} + N_{V,t} + N_{H,t}^*)^{\frac{1}{1-\theta}} \widetilde{P}_t \text{ and } P_t^* = (N_{D,t}^* + N_{H,t})^{\frac{1}{1-\theta}} \widetilde{P}_t^* \quad (1.35)$$

Thus, I write the CPI-based real exchange rate as:³⁹

$$\widetilde{Q}_t^{1-\theta} = \left(\frac{N_{D,t} + N_{V,t} + N_{H,t}^*}{N_{D,t}^* + N_{H,t}} \right) \frac{N_{D,t}^* \left(\frac{TOL_t}{\widetilde{z}_{D,t}^*} \right)^{1-\theta} + N_{H,t} \left(\frac{\tau_t^*}{\widetilde{z}_{H,t}} \right)^{1-\theta}}{N_{D,t} \left(\frac{1}{\widetilde{z}_{D,t}} \right)^{1-\theta} + N_{V,t} \left(\frac{\tau_t TOL_t}{\widetilde{z}_{V,t}} \right)^{1-\theta} + N_{H,t}^* \left[\frac{\tau_t TOL_t}{\widetilde{z}_{H,t}^*} \right]^{1-\theta}}, \quad (1.36)$$

where the terms of labor $TOL_t = \frac{Q_t w_t^* / Z_t^*}{w_t / Z_t}$ measure the cost of effective labor in the South relative to the North; the iceberg trade costs τ_t and τ_t^* (which I allow to vary over time) affect imports into the North and South, respectively. The expression nests the model with endogenous exports of GM2005; I shut down offshoring and revisit the GM2005 case when $N_{V,t} = 0$.

³⁸Variable $N_{D,t}$ represents the number of final good varieties produced by Northern firms domestically and sold in the Northern market; $N_{V,t}$ represents varieties produced by Northern firms offshore and sold in the North; and $N_{H,t}^*$ reflects varieties produced by Southern firms and exported to the North. It follows that $\widetilde{Q}_t^{1-\theta} = \left(\frac{N_{D,t} + N_{V,t} + N_{H,t}^*}{N_{D,t}^* + N_{H,t}} \right) Q_t^{1-\theta}$.

³⁹The CPI-based real exchange rate \widetilde{Q}_t deviates from the welfare-based real exchange rate $Q_t = \varepsilon_t P_t^* / P_t$ due to cross-country differences in product variety. As discussed in GM2005, an appreciation of the CPI-based real exchange rate \widetilde{Q}_t (i.e. an increase in the CPI in North relative to that in South) may be offset by the increase in product variety in North ($N_{D,t} + N_{V,t} + N_{H,t}^*$) relative to South ($N_{D,t}^* + N_{H,t}$), so that the welfare-based real exchange rate Q_t depreciates (i.e. despite the increase in average prices, consumers derive higher utility due to the larger product variety).

Analytical results While allowing for offshore production and nesting the benchmark model with exports only as in GM2005, I log-linearize (1.36) to obtain:⁴⁰

$$\widehat{Q}_t = [s_D - s_V + s_D^* - 1] \widehat{TOL}_t + \quad (\text{C1})$$

$$+ (s_D - s_V) \widehat{z}_{D,t} + s_V \widehat{z}_{V,t} - (1 - \alpha) s_V \widehat{\tau}_t + \quad (\text{C2})$$

$$+ (1 - s_D) (\widehat{z}_{H,t}^* - \widehat{\tau}_t) - (1 - s_D^*) (\widehat{z}_{H,t} - \widehat{\tau}_t^*) + \quad (\text{C3})$$

$$+ \frac{1}{\theta - 1} \left(s_V - \frac{N_V}{N_D + N_V + N_H^*} \right) (\widehat{N}_{V,t} - \widehat{N}_{H,t}^*) + \quad (\text{C4})$$

$$+ \frac{1}{\theta - 1} \left[\begin{array}{l} \left(\frac{N_D^*}{N_D^* + N_H} - s_D^* \right) (\widehat{N}_{D,t}^* - \widehat{N}_{H,t}) - \\ - \left(\frac{N_D}{N_D + N_V + N_H^*} - (s_D - s_V) \right) (\widehat{N}_{D,t} - \widehat{N}_{H,t}^*) \end{array} \right], \quad (\text{C5})$$

where parameter s_D is the steady-state share of spending in the North on goods produced by Northern firms *both* domestically and offshore; s_V is the steady-state share of spending in the North *only* on goods produced by Northern firms offshore (I revisit GM2005 when $s_V = 0$); s_D^* is the steady-state share of spending in the South on goods produced by Southern firms domestically. The calibration of the model ensures that: (a) $(s_D - s_V) + s_D^* > 1$, as the domestically-produced varieties represent more than 50 percent of the consumption spending in each country; (b) $\left(\frac{N_D}{N_D + N_V + N_H^*} - (s_D - s_V) \right) > 0$ and $\left(\frac{N_D^*}{N_D^* + N_H} - s_D^* \right) > 0$, i.e. the market shares of varieties produced domestically by *the less productive* firms are *smaller* than their fraction in the total number of varieties; and (c) finally, $\left(s_V - \frac{N_V}{N_D + N_V + N_H^*} \right) > 0$, i.e. the market share of varieties produced offshore by *the more productive* Northern firms is *larger* than their fraction in the total number of varieties available in the North. Thus, the model implies that the more productive firms are larger and have larger market shares

⁴⁰See the Appendix for the derivation.

than their less productive counterparts, which is in line with the empirical evidence in Kurz (2006).

The log-linearized form of (1.36) outlines five channels (labeled C1-C5 in the log-linearized expression above) through which the CPI-based real exchange rate is affected by: (1) changes in the price of non-tradable goods induced by fluctuations in the terms of labor (\widehat{TOL}_t); (2) changes in the price of offshored goods reflecting fluctuations in the average productivity of offshoring firms ($\widehat{z}_{V,t}$) and in the magnitude of trade costs ($\widehat{\tau}_t$); (3) changes in the relative import prices triggered by fluctuations in the average productivity of Northern exporters ($\widehat{z}_{H,t}$) relative to that of their Southern counterparts ($\widehat{z}_{H,t}^*$); (4) changes in the relative availability of varieties produced by Northern offshoring firms ($\widehat{N}_{V,t}$) relative to that of Southern exported varieties ($\widehat{N}_{H,t}^*$); and (5) changes in the relative availability of domestic varieties ($\widehat{N}_{D,t}$) relative to that of Southern exported varieties ($\widehat{N}_{H,t}^*$).

Impulse responses I find that, relative to the benchmark model with endogenous exports in GM2005, offshoring dampens the appreciation of the real exchange rate following an aggregate productivity improvement in the North. Specifically, the effect occurs through channels C1 (the price of non-traded goods), C3 (the relative import prices) and C4 (the availability of offshored varieties vs. Southern imported varieties). The impulse responses for the variables of interest are outlined in Figure 5; their impact on the real exchange rate is described next.

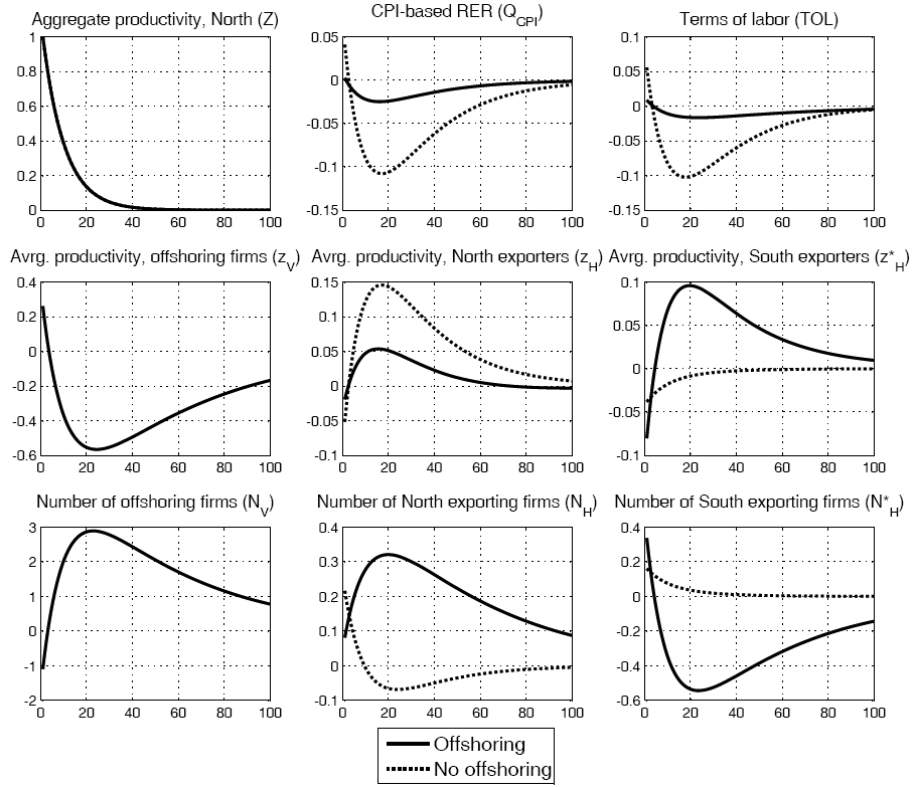


Figure 5. Endogenous offshoring (continuous line) vs. exports only (dotted line),

impulse responses to a transitory 1 percent increase in aggregate productivity in the North

(C1) Changes in the price of non-traded goods. In the benchmark model with endogenous exports and no offshoring, a productivity increase in the North encourages firm entry and leads to the appreciation of the terms of labor in the medium run (i.e. TOL_t decreases). In turn, this causes the average price of non-traded goods in the North to increase relative to that in the South, and thus leads to the appreciation of the real exchange rate (i.e. \tilde{Q}_t decreases).

In my model, offshoring dampens the appreciation of the real exchange rate taking effect

through this channel in two ways: (a) Offshoring reduces the share of non-traded goods in total spending ($s_D - s_V$) as $s_V > 0$; (b) Offshoring also dampens the appreciation of the terms of labor relative to the benchmark model with exports only (i.e. TOL_t decreases by less), as the relocation of production offshore transfers upward pressure from the domestic wage onto the foreign one.

(C2) Changes in the price of offshored goods. On impact, due to the initial spike in the Southern wage (caused by the increase in offshoring along its intensive margin), the number of offshoring firms declines and their average productivity rises. In the medium run, however, due to the appreciation of the cost of effective labor in the North relative to the South, offshoring becomes a more profitable option. Thus, the average productivity $\tilde{z}_{V,t}$ of offshoring firms declines and their average price increases. Offshoring contributes to the appreciation of the real exchange rate through this channel.

Exogenous policy changes can also affect the price of goods produced offshore. For instance, tariff cuts for the varieties of final goods produced offshore (i.e. a policy measure reflected by a decrease in τ_t) would dampen the appreciation of the CPI-based real exchange rate.

(C3) Changes in relative import prices. In the benchmark model with exports only, the appreciation of the terms of labor reduces the export profitability of the Northern firms relative to that of their Southern counterparts. In turn, the average productivity of the surviving Northern exporters ($\tilde{z}_{H,t}$) increases relative to that of the Southern exporters ($\tilde{z}_{H,t}^*$), and the average price of the Southern imports to decline relative to that of the Northern imports. This causes the real exchange rate to appreciate.

Offshoring reverses this effect. The upwards pressure on the Southern wage causes

the export profitability of the Southern firms to decline, and thus the productivity of the surviving Southern exporters to increase by more than that of their Northern counterparts. In contrast to the benchmark model with exports only, offshoring causes the average price of the Northern imports to decline relative to the average price of the Southern imports, a result which dampens the appreciation of the real exchange rate through import prices.

(C4) Expenditure switching from imports towards offshored goods. Following an increase in aggregate productivity, offshoring puts upward pressure on the Southern wage and reduces the competitiveness of the Southern exports. Thus, Northern consumers switch their expenditure away from the increasingly less competitive Southern varieties ($N_{H,t}^*$ decreases) and towards the relatively cheaper varieties produced by Northern firms offshore ($N_{V,t}$ increases). The result dampens the appreciation of the real exchange rate in the medium run. It is consistent with the empirical evidence that FDI inflows in Mexico between 1994 and 2002 were associated with the crowding out of domestic investment, particularly in manufacturing (Gallagher and Zarsky, 2007).

(C5) Expenditure switching from imports towards domestic goods. Firm entry in the North generates an increase in the number of domestic varieties ($N_{D,t}$) relative to foreign imported varieties ($N_{H,t}^*$) available to Northern consumers. In turn, consumers switch their expenditures from imports towards the final good varieties produced domestically by the relatively less productive firms, and which are available at relatively higher average prices. As in the model with exports only, this channel works towards the appreciation of the real exchange rate.

1.5.3 Empirical Moments: The Cyclicity of Offshoring

In this section I show that offshore production in Mexico's maquiladora sector is pro-cyclical with fluctuations in the U.S. manufacturing output. The result is robust across several indicators of offshoring: real value added, hours worked, and the number of establishments in the maquiladora sector. The finding invites the construction of the model in which offshore production is procyclical with domestic output, and in which the extensive margin of offshoring (proxied empirically by the number of maquiladora establishments) plays a special role in the cross-country transmission of business cycle fluctuations.

The absence of local consumption and the dominant share of the U.S. as the destination market make Mexico's maquiladora sector an appropriate empirical setup to study the cyclicity of offshoring through vertical FDI. By definition, plants operating under Mexico's maquiladora program import inputs, process them, and ship the resulting goods back to the country of origin (Gruben, 2001). Although not all plants in Mexico's maquiladora sector are owned by U.S. firms, most of the maquiladora's imported inputs (82 percent in 2001) originate in the U.S. (Hausman and Haytko, 2003), and most of the maquiladora's value added (roughly 90 percent) is exported to the U.S. (Burstein, Kurz, Tesar, 2007).

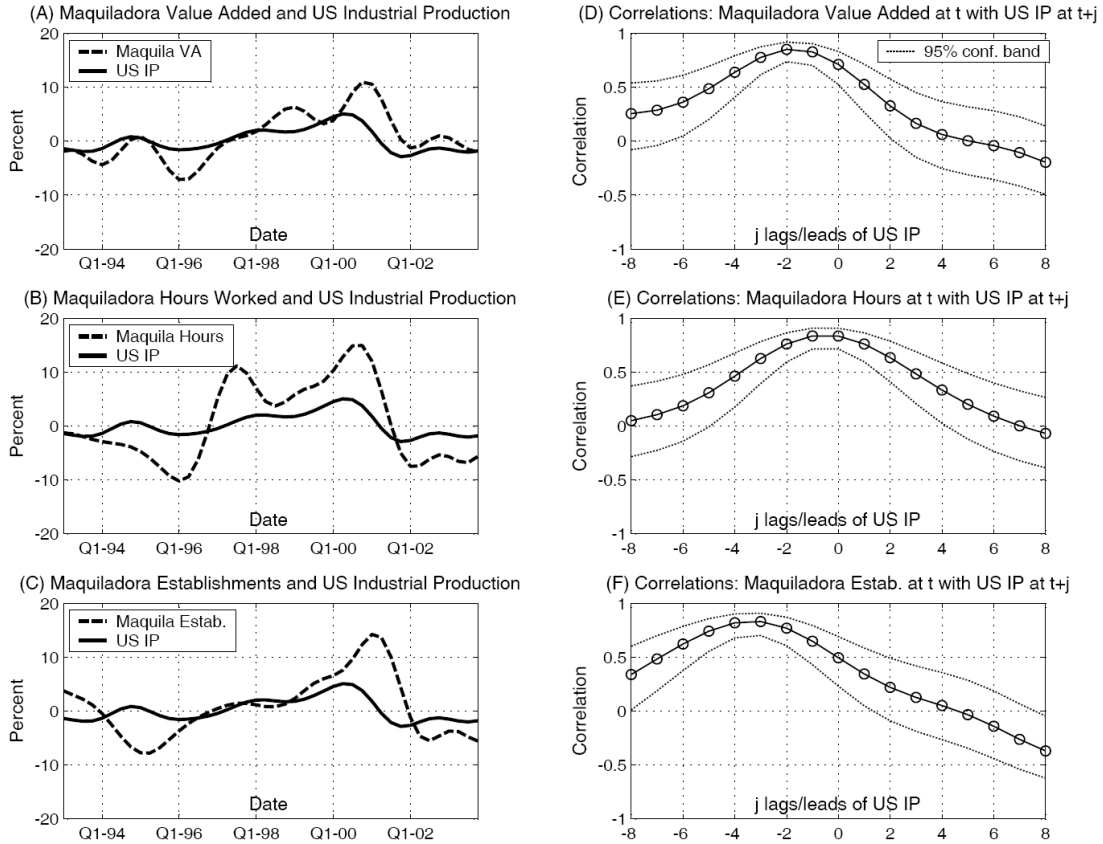


Figure 6. Mexico's maquiladora and U.S. manufacturing industrial production

In panels A-C of Figure 6 (left) I plot the three maquiladora indicators (real value added, total hours worked, and the number of establishments) against the industrial production index for U.S. manufacturing.⁴¹ I apply the Baxter-King bandpass-filter⁴¹ to the quarterly data in natural logs for the interval 1990:1-2006:4 in order to eliminate fluctuations with

⁴¹I use quarterly data for the interval between 1990:1 and 2006:4. The data for U.S. manufacturing (i.e. seasonally adjusted real industrial production and the nominal hourly wage in manufacturing) is provided by the Board of Governors of the Federal Reserve System and by the U.S. Bureau of Labor Statistics. Data for Mexico's maquiladora sector (real value added, hours worked and the number of plants), at monthly frequency and without seasonal adjustment, is provided by the Instituto Nacional de Estadística y Geografía (INEGI), Mexico. Thus, I take the quarterly averages of the Mexican data and perform the seasonal adjustment using the X-12-ARIMA method of the U.S. Census Bureau.

periodicity lower than 18 months and greater than eight years. The visual inspection of the filtered data suggests that the U.S. economic expansion throughout the 1990s, as well as the recession in 2001, were associated with similar developments in the maquiladora sector. Also, the unconditional correlations summarized in panels D-F of Figure 6 (right) suggest that offshoring to Mexico is procyclical with fluctuations in U.S. manufacturing. In particular, the correlations of offshoring with lags and leads of the U.S. manufacturing index suggest that U.S. output is contemporaneously correlated with the number of hours worked in the maquiladora sector, whereas it tends to lead the number of maquiladora establishments (offshoring at the extensive margin) by at least three quarters.⁴²

1.5.4 Theoretical Moments: The Cyclicity of Offshoring

Theoretical measures of offshoring In this section I explore the ability of the model to replicate the cyclicity of offshoring to Mexico’s maquiladora industry relative to fluctuations in U.S. manufacturing. Using the usual demand and price functions under monopolistic competition for the varieties produced offshore, the total value added contributed by offshore affiliates is:⁴³

$$VA_t = N_{V,t} \left[\frac{\theta}{\theta - 1} \frac{w_t \tau_t TOL_t}{Z_t \tilde{z}_{V,t}} \right]^{1-\theta} C_t, \text{ with } \theta > 1. \quad (1.37)$$

⁴² Although the interval of three quarters may appear too short for the creation of new offshore plants, this finding must be considered in light of the fact that a considerable fraction of the non-U.S. owned maquiladora plants represent arm’s length contractors that have the flexibility to enter into and exit from outsourcing relationships with U.S. firms over the business cycle.

⁴³ To compute moments, I deflate the value added offshore by the average CPI in the North economy in order to eliminate the variety effect, i.e. $(VA)_{R,t} = P_t (VA_t) / \tilde{P}_t$, where $P_t = N_t^{\frac{1}{1-\theta}} \tilde{P}_t$.

In particular, I measure the *extensive margin* as the number of offshoring firms every period, $N_{V,t}$, and the *intensive margin* of offshoring as the real value added per offshoring firm, $VA_{R,t}/N_{V,t}$.

The determinants of offshoring Using the expression for total value added in (1.37), and holding fixed the cost of effective labor in the North, the following regularities become apparent: (a) The value added offshore decreases with the terms of labor ($\partial VA_t / \partial TOL_t < 0$): the higher is the cost of effective labor in the South relative to the North, the lower is the incentive to produce offshore; (b) Offshoring decreases with the trade cost affecting the shipping of goods produced offshore back to the country of origin ($\partial VA_t / \partial \tau_t < 0$), as the trade cost reflects the magnitude of tariffs, trade barriers, transportation and insurance costs; (c) The value added offshore increases with the average productivity of the offshoring firms ($\partial VA_t / \partial \tilde{z}_{V,t} > 0$); (d) The value added offshore also depends on the number of offshoring firms every period ($\partial VA_t / \partial N_{V,t} > 0$), which is inversely related to the fixed cost of offshoring (f_V). The predictions of the model are in line with the empirical evidence provided by Hanson, Mataloni and Slaughter (2005) that the demand for imported inputs by U.S. multinational firms increases when their offshore affiliates benefit from relatively lower low-skilled foreign wages and face lower trade costs.

The productivity process I introduce elastic labor supply in the baseline model of offshoring under financial autarky, using the standard calibration described above. I also assume that aggregate productivity in the North and in the South follow a bivariate

autoregressive process:

$$\begin{bmatrix} \log Z_t \\ \log Z_t^* \end{bmatrix} = \begin{bmatrix} \rho_Z & \rho_{ZZ^*} \\ \rho_{Z^*Z} & \rho_{Z^*} \end{bmatrix} \begin{bmatrix} \log Z_{t-1} \\ \log Z_{t-1}^* \end{bmatrix} + \begin{bmatrix} \xi_t \\ \xi_t^* \end{bmatrix}, \quad (1.38)$$

and that the productivity shocks are the only source of international business cycles in the model. Following Backus, Kehoe, and Kydland (1992), I set the persistence parameters to $\rho_Z = \rho_{Z^*} = 0.906$, and the spillover parameters to $\rho_{ZZ^*} = \rho_{Z^*Z} = 0.088$; the variance of the shocks is 0.00852 and the covariance is $0.18728 * 10^{-4}$, values which correspond to a correlation of innovations of 0.258.

Empirical vs. theoretical correlations Table 3 (panel A) provides the empirical moments of offshoring from U.S. manufacturing to Mexico’s maquiladora sector. It includes the empirical correlations of the maquiladora indicators (total value added, the number of establishments, and the total value added per establishment) with lags and leads of the industrial production index for U.S. manufacturing.⁴⁴ In addition, Figure 7 contrasts the empirical moments with their theoretical counterparts generated by the model.

The model is successful in generating the procyclical variation in the total value added offshore relative to fluctuations in U.S. manufacturing output (Table 3). The contemporaneous correlation between the offshore value added and manufacturing output in the North (0.78) is remarkably close to the corresponding empirical correlation between the value added in Mexico’s maquiladora and U.S. manufacturing output (0.71).

⁴⁴I use the number of establishments in the maquiladora sector as an empirical proxy for the extensive margin of offshoring, and the real value added per establishment as an empirical proxy for the intensive margin.

**Table 3. Correlations of the maquiladora variables at t
with GDP in North (y_R) at $t + j$**

j	-8	-6	-4	-2	0	+2	+4	+6	+8
A. Empirical correlations with lags and leads of U.S. manufacturing IP									
Total V.A.	0.26	0.36	0.64	0.85	0.71	0.33	0.06	-0.04	-0.20
Establishments	0.34	0.62	0.82	0.77	0.49	0.22	0.05	-0.14	-0.37
V.A. per establ.	-0.23	-0.55	-0.51	-0.16	0.08	0.06	0.00	0.16	0.30
B. Model with elastic labor supply under financial autarky									
Total V.A.	-0.04	0.09	0.28	0.51	0.78	0.86	0.92	0.93	0.93
Firms	0.28	0.41	0.45	0.31	-0.19	-0.16	-0.11	-0.07	-0.03
V.A. per firm	-0.29	-0.40	-0.43	-0.26	0.27	0.25	0.20	0.16	0.12

Turning towards the extensive margin (Figure 7, panel A), the data shows a strong and positive correlation between the number of maquiladora establishments and *past* U.S. manufacturing output, a result which suggests that U.S. economic expansions tend to lead the number of establishments by at least three quarters. The model is successful qualitatively in capturing this pattern: the correlation between the number of offshoring firms and *past* output in the North is positive (it peaks for Northern output lagged by four quarters). This theoretical result is caused by the fact that, following a productivity improvement in the North, offshoring increases along its extensive margin gradually over time. This pattern mirrors the gradual appreciation of the Northern wage caused by domestic firm entry.

The model deviates from the empirical evidence in that the contemporaneous correlation

between the number of offshoring firms and output in the North is negative (rather than positive as in the data). On impact, the greater demand for Southern varieties causes the Southern wage to spike upwards, thus reducing the number of offshoring firms and generating a negative contemporaneous correlation between the number of offshoring firms and Northern output. The introduction of a sunk offshoring cost in the model (to replace the fixed, per-period offshoring cost) would probably help address this issue.

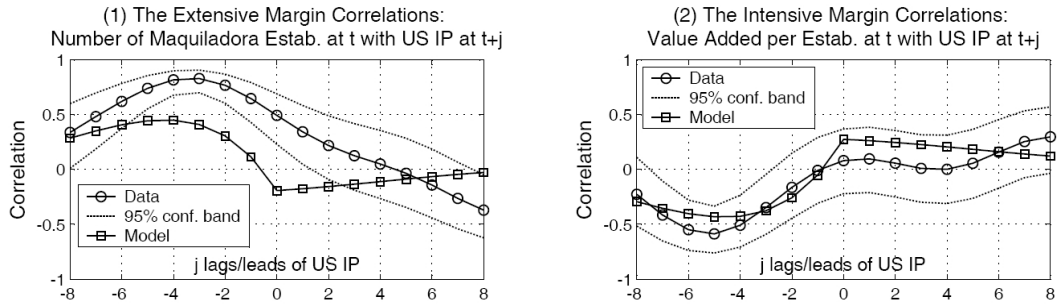


Figure 7. Empirical vs. theoretical moments, financial autarky with elastic labor supply

Regarding the intensive margin (Figure 7, panel B), the empirical correlation between value added per maquiladora establishment and the past manufacturing output is negative and statistically significant. The model is successful in replicating this pattern as well: The theoretical correlation between the intensive margin and past output in the North is negative, as the value added per offshoring firm declines below its initial level several quarters after the increase in aggregate productivity in the North (i.e. the number of offshoring firms increases faster than the total value added offshore).

1.5.5 Theoretical Moments: Cross-Country Co-movement of Output and Consumption

In this section I examine the cross-country correlations of national income and consumption generated by the model with offshoring relative to those from the model with exports only. I also conduct sensitivity analysis for a range of possible values of the key model parameters. Under the baseline framework of offshoring with financial autarky, I assume that productivity follows the bivariate autoregressive process in (1.38), and that aggregate productivity shocks are the only sources of business cycle fluctuations.

The productivity process For the matrix of persistence and spillover coefficients describing the bivariate productivity process, I use parameter values that are in line with the international real business cycle literature. In particular, I focus on three cases: (1) Low persistence ($\rho_Z = \rho_{Z^*} = 0.906$) and positive spillover parameters ($\rho_{ZZ^*} = \rho_{Z^*Z} = 0.088$) as in Backus, Kehoe, and Kydland (1992, 1994); (2) Near-unit persistence ($\rho_Z = \rho_{Z^*} = 0.999$) and zero spillovers as in Baxter and Farr (2005), with the variance of shocks 0.00852 and covariance $0.18728 * 10^{-4}$ (correlation 0.26) as in Backus, Kehoe, and Kydland (1992); (3) Asymmetric persistence ($\rho_Z = 0.996$ and $\rho_{Z^*} = 0.951$) and zero spillovers, with the shocks being more volatile in Mexico than in the U.S. (i.e. variances 0.0139570^{-2} vs. 0.0050939^{-2}) and covariance $0.1898 * 10^{-4}$ (correlation 0.27), as estimated in Mandelman and Zlate (2008) using total factor productivity (TFP) data for the U.S. and Mexico.

Table 4 shows the cross-country correlations of output $Corr(Y_R, Y_R^*)$ and consumption $Corr(C_R, C_R^*)$, both for the model with offshoring (OFFSH) and for the benchmark model with exports only as in GM2005 (NO OFFSH), for each of the three productivity speci-

cations described above.⁴⁵ The results show that offshoring enhances the cross-country co-movement of both output and consumption relative to the benchmark model with exports. In particular, under the specification with near-unit persistence, the model with offshoring under financial autarky reverses the ranking of correlations (the cross-country correlation of output exceeds that of consumption), thus addressing the output-consumption correlation puzzle observed in the international real business cycle literature, as discussed in Backus, Kehoe, and Kydland (1992, 1994).

Table 4. Output and consumption co-movement, financial autarky

Calibration:	(1) Low persistence, $\rho_Z = \rho_{Z^*} = 0.906$	(2) High persistence, $\rho_Z = \rho_{Z^*} = 0.999$	(3) Asymm. persistence, $\rho_Z = 0.996, \rho_{Z^*} = 0.951$
Model:	OFFSH NO OFFSH	OFFSH NO OFFSH	OFFSH NO OFFSH
$Corr(Y_R, Y_R^*)$	0.41 0.39	0.33 0.25	0.35 0.27
$Corr(C_R, C_R^*)$	0.96 0.92	0.32 0.28	0.40 0.28

Sensitivity to ρ, θ, τ I also check the sensitivity of the cross-country correlations of output and consumption to variations in the following parameters: (a) the persistence of the bivariate autoregressive productivity process ρ_Z (with zero spillovers); (b) the elasticity of substitution between the Northern and Southern final good varieties θ ; and (c) the iceberg trade cost τ .

The results in Figure 8 show that the model with offshoring under financial autarky

⁴⁵In order to compute the cross-country correlations of national income and consumption, I deflate the corresponding variables by the average price indices in each country. For instance, I deflate the national income in North as $Y_{R,t} = P_t Y_t / \tilde{P}_t$, where $P_t = (N_{D,t} + N_{V,t} + N_{H,t}^*)^{\frac{1}{\theta-1}} \tilde{P}_t$, since the empirical price deflators are best represented by the average price index \tilde{P}_t rather than the welfare-based price index P_t , as discussed in Ghironi and Melitz (2005).

generates larger cross-country correlations for both output and consumption relative to the benchmark model with exports, a result which holds for a wide range of values for the persistence parameter $\phi_Z \in [0.9, 1)$, the elasticity of substitution $\theta \in [2.5, 4.1]$ and the iceberg trade cost $\tau \in [1.20, 1.33]$. In particular, the cross-country correlation of output decreases with the iceberg trade cost. Following a positive shock in the North, a larger trade cost dampens the firms' incentive to relocate production offshore, which leads to a lower co-movement of output. The result is in line with the stylized facts documented in Burstein, Kurz, and Tesar (2007), namely that countries involved in offshoring more intensely tend to display higher correlations of manufacturing output.

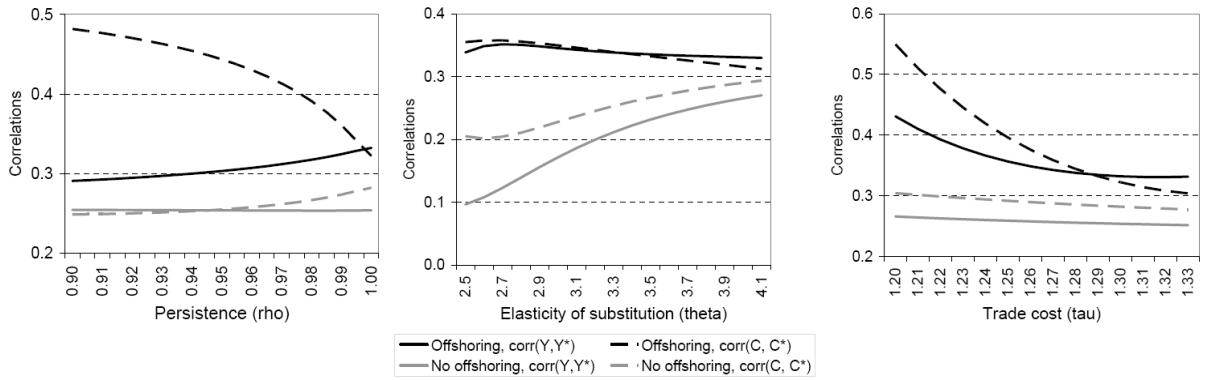


Figure 8. Offshoring under financial autarky: co-movement sensitivity to ρ_Z , θ and τ .

1.5.6 Theoretical Moments: Offshoring and the Macroeconomy

Table 5 compares the theoretical moments generated by the model with offshore production (panel B) and those generated by the model with exports only (and no offshoring) as in GM2005 (panel C), under the baseline framework with inelastic labor supply augmented with *international trade in bonds*. (The equations are described in Appendix 2.) The empirical moments reported in the table are those computed in Mandelman and Zlate

(2008) based on data for the U.S. and Mexico. I assume that productivity follows the bivariate productivity process in 1.38, with the persistence parameter $\rho_Z = \rho_{Z^*} = 0.906$, positive spillover parameters $\rho_{ZZ^*} = \rho_{Z^*Z} = 0.088$, the variance of shocks 0.00852 and the covariance $0.18728 * 10^{-4}$, as in Backus, Kehoe, and Kydland (1992, 1994).

The results are largely similar to the ones in GM2005, with a couple of exceptions that I discuss here. First, in the presence of offshoring, investment in the North becomes more pro-cyclical with the Northern output. The correlation between output and investment in the North (where the latter is measured as both total investment in firm entry and the number of new entrant firms) is larger in the model with offshoring (0.89 for each) than in the model with exports only (0.86 and 0.87, respectively). The result is due to the fact that, when offshoring is available as a low-cost alternative to domestic production, the expected profitability of potential entrants in the Northern economy increases, and so do investment and firm entry. In turn, the employment loss caused by offshoring is partially offset by the employment gain generated by stronger firm entry in the presence of offshoring. (The result is in line with the employment dynamics discussed in Appendix 3).

Table 5. Offshoring and the macroeconomy: empirical vs. theoretical moments

	Absolute std. dev.		Relative std. dev.		Correlations with output in:		Other correlations	
(a) Empirical moments								
	U.S.	Mex	U.S.	Mex	U.S.	Mex		
Output	1.24	2.32	1.00	1.00	–	–	y_R, y_R^*	0.16
Consumption	0.93	2.84	0.75	1.23	0.83	0.92	C_R, C_R^*	-0.04
Investment	4.18	9.26	3.36	4.00	0.90	0.90	I, I^*	0.21
Trade Bal./GDP	0.33	1.47	0.26	1.47	-0.42	-0.72	$\frac{C_R}{C_R^*}, Q_{CPI}$	-0.47
(b) Offshoring, financial integration								
	North	South	North	South	North	South		
Output	0.95	0.92	1.00	1.00	–	–	y_R, y_R^*	0.40
Consumption	0.64	0.60	0.67	0.65	0.91	0.87	C_R, C_R^*	0.97
Investment	3.23	4.33	3.40	4.71	0.89	0.82	$\tilde{v}_R^E, \tilde{v}_R^{E*}$	-0.56
Firm entry	3.26	4.40	3.43	4.78	0.89	0.83	$\frac{y_R - C_R}{y_R}, \frac{\tilde{v}_R^E}{y_R}$	0.97
Trade bal./GDP	0.10	0.11	0.11	0.12	-0.12	0.20	$\frac{C_R}{C_R^*}, Q_{CPI}$	0.14
CPI-based RER	0.06		0.06				$\frac{C}{C_R}, Q$	0.74
							TB_R, VA_R	-0.23
(c) No offshoring (GM2005), financial integration								
	North	South	North	South	North	South		
Output	0.95	0.92	1.00	1.00	–	–	y_R, y_R^*	0.40
Consumption	0.65	0.61	0.68	0.66	0.91	0.89	C_R, C_R^*	0.96
Investment	3.64	3.83	3.83	4.16	0.86	0.84	$\tilde{v}_R^E, \tilde{v}_R^{E*}$	-0.55
Firm entry	3.66	3.93	3.85	4.27	0.87	0.85	$\frac{y_R - C_R}{y_R}, \frac{\tilde{v}_R^E}{y_R}$	0.97
Trade bal./GDP	0.11	0.11	0.12	0.12	-0.10	-0.04	$\frac{C_R}{C_R^*}, Q_{CPI}$	-0.02
CPI-based RER	0.04		0.04				$\frac{C}{C_R}, Q$	0.74

Second, the trade balance for the North becomes more counter-cyclical in the model with offshoring than in the benchmark model with exports only: The correlation between

the relative trade balance and output in the North is more negative with offshoring (-0.12) than with exports only (-0.10). The correlation between the offshore value added and the trade balance is also negative (-0.23). The result is due to the fact that the imports of offshored varieties contribute to the expanding trade deficit that follows a productivity increase in the North; also, the stronger domestic firm entry in the presence of offshoring increases lending from the South to the North.

Nonetheless, when allowing for international trade in bonds, there is no notable increase in the co-movement of output in the model with offshoring relative to the model with exports only. The transfer of resources through lending towards the more productive Northern economy (and the resulting decline in Southern output) offsets the enhanced co-movement generated by offshoring.

1.6 Conclusion

In this paper I study the way in which the relocation of production to other countries alters the cross-country transmission of business cycles. In particular, I focus on the fluctuations in the extensive and intensive margins of offshoring (the number of firms and the value added per firm, respectively) as separate transmission mechanisms, and analyze their impact on output, wages and relative prices in the parent and the host country. Thus, my study adds to the theoretical literature of macroeconomics and international trade that abstracts from the business cycle dynamics of offshore production along its extensive and intensive margins. In my model, offshore production is determined endogenously in the presence of domestic firm entry and heterogeneity in labor productivity across firms. Offshoring depends on the

difference between the domestic and foreign cost of effective labor, on the firm-specific labor productivity, as well as on the fixed and iceberg trade costs.

The key results of the paper are as follows. First, the model is successful in replicating the pro-cyclical pattern of offshoring as well as the dynamics of offshoring along the extensive and intensive margins, which I document using data from Mexico's maquiladora sector. Following an aggregate productivity increase in the country of origin, the amount of value added per offshoring firm (the intensive margin) spikes upward on impact, and decreases afterwards. In the medium run, however, domestic firm entry causes the domestic wage to increase faster than aggregate productivity, which in turn determines some of the more productive firms to relocate production offshore. The gradual response of the number of offshoring firms (the extensive margin) mirrors the steady appreciation of the cost of effective labor that follows domestic firm entry. Thus, the model is consistent with the empirical regularity that expansions in U.S. manufacturing output precede increases in the number of offshore plants in Mexico's maquiladora sector.

Second, offshoring enhances the cross-country co-movement of output relative to the model with endogenous exports. As firm entry in the parent country leads to the appreciation of the terms of labor, the increasing demand for domestic labor (due to firm entry) and sequentially the increasing demand for labor offshore (due to the relocation of production) enhance the co-movement of wages and aggregate incomes. The result is consistent with the stylized fact outlined in Burstein, Kurz, and Tesar (2008), that countries with stronger production sharing trade links tend to display a closer co-movement of manufacturing output.

Third, offshoring reduces the price level gap between the countries involved, because it

dampens the appreciation of the real exchange rate that follows an aggregate productivity improvement in the parent country (the Harrod-Balassa-Samuelson effect) through several channels: In particular, (i) offshoring transfers some of the upward pressure from the domestic wage (caused by domestic firm entry) onto the foreign wage (through the relocation of production), and thus dampens the appreciation of the terms of labor; (ii) offshoring leads to a decrease in the average import prices; and (iii) offshoring crowds out the less competitive foreign exporters.

I recognize the possibility for several interesting extensions to this paper. First, the model provides a useful framework to analyze the impact of offshore production on employment and wages, both in the parent and in the host countries. The preliminary analysis of employment dynamics in Appendix 3 shows that, as offshoring enhances firm entry in the parent country, the domestic job loss caused by offshoring is partially offset by the creation of new jobs associated with new product varieties. Second, the model allows to study the welfare implications of offshoring and trade liberalization, as discussed in Appendix 4. Third, in an empirical extension of this paper, I study the dynamic response of the extensive and intensive margins of offshore production in Mexico's maquiladora sector to long-run labor productivity shocks in U.S. manufacturing, which I identify as permanent, country-specific technology shocks (see Chapter 2 of this Dissertation). Fourth and finally, one extension with rich policy implications involves the study of interactions between offshore production and labor migration within an integrated framework, in which both offshoring and labor mobility are driven by fluctuations in relative wages (for the study of labor migration, see Chapter 3 of this Dissertation).

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1.A Appendix

1.A.1 Summary: Model of Offshoring with Financial Autarky

Table A.1.

Euler equation, bonds	$C_t^{-\gamma} = \beta (1 + r_{t+1}) E_t \left[C_{t+1}^{-\gamma} \right]$ $C_t^{*\,-\gamma} = \beta (1 + r_{t+1}^*) E_t \left[C_{t+1}^{*\,-\gamma} \right]$
Euler equation, stocks	$\tilde{v}_t = \beta(1 - \delta) E_t \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} (\tilde{d}_{t+1} + \tilde{v}_{t+1})$ $\tilde{v}_t^* = \beta^*(1 - \delta^*) E_t \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\gamma} (\tilde{d}_{t+1}^* + \tilde{v}_{t+1}^*)$
Free entry	$\tilde{v}_t = \frac{f_E w_t}{Z_t}$ $\tilde{v}_t^* = \frac{f_E^* w_t^*}{Z_t^*}$
Rule of motion, # firms	$N_{t+1} = (1 - \delta)(N_t + N_{E,t})$ $N_{D,t+1}^* = (1 - \delta)(N_{D,t}^* + N_{E,t}^*)$
Aggregate accounting	$C_t + N_{E,t} \tilde{v}_t = w_t L + N_t \tilde{d}_t$ $C_t^* + N_{E,t}^* \tilde{v}_t^* = w_t^* L^* + N_{D,t}^* \tilde{d}_t^*$
Consumption price index	$1 = N_{D,t} (\tilde{\rho}_{D,t})^{1-\theta} + N_{V,t} (\tilde{\rho}_{V,t})^{1-\theta} + N_{H,t}^* (\tilde{\rho}_{H,t}^*)^{1-\theta}$ $1 = N_{D,t}^* (\tilde{\rho}_{D,t}^*)^{1-\theta} + N_{H,t} (\tilde{\rho}_{H,t})^{1-\theta}$
Total profits	$N_t \tilde{d}_t = N_{D,t} \tilde{d}_{D,t} + N_{V,t} \tilde{d}_{V,t} + N_{H,t} \tilde{d}_{H,t}$ $N_{D,t}^* \tilde{d}_t^* = N_{D,t}^* \tilde{d}_{D,t}^* + N_{H,t}^* \tilde{d}_{H,t}^*$
Number of firms (Home)	$N_t = N_{D,t} + N_{V,t}$
VFDI profits link (Home)	$\tilde{d}_{V,t} = \frac{k}{k - (\theta - 1)} \left(\frac{z_{V,t}}{\tilde{z}_{D,t}} \right)^{\theta - 1} \tilde{d}_{D,t} + \frac{\theta - 1}{k - (\theta - 1)} f_V \frac{w_t^* Q_t}{Z_t^*}$
HFDI profits link	$\tilde{d}_{H,t} = \frac{\theta - 1}{k - (\theta - 1)} f_H \frac{w_t}{Z_t}$ $\tilde{d}_{H,t}^* = \frac{\theta - 1}{k - (\theta - 1)} f_H^* \frac{w_t^*}{Z_t^*}$
Dom. productivity (Home)	$\tilde{z}_{D,t} = \nu z_{\min} z_{V,t} \left[\frac{z_{V,t}^{k - (\theta - 1)} - z_{\min}^{k - (\theta - 1)}}{z_{V,t}^k - z_{\min}^k} \right]^{\frac{1}{\theta - 1}}$
VFDI productivity (Home)	$\tilde{z}_{V,t} = \nu z_{\min} \left(\frac{N_t}{N_{V,t}} \right)^{1/k}$
HFDI productivity	$\tilde{z}_{H,t} = \nu z_{\min} \left(\frac{N_t}{N_{H,t}} \right)^{1/k}$ $\tilde{z}_{H,t}^* = \nu z_{\min}^* \left(\frac{N_{D,t}^*}{N_{H,t}^*} \right)^{1/k}$
Balanced trade	$N_{H,t} (\tilde{\rho}_{H,t})^{1-\theta} C_t^* Q_t + N_{V,t} \tilde{d}_{V,t} =$ $= N_{V,t} (\tilde{\rho}_{V,t})^{1-\theta} C_t + N_{H,t}^* (\tilde{\rho}_{H,t}^*)^{1-\theta} C_t$

The baseline model with financial autarky for the Northern economy is summarized by 16 equations in 16 endogenous variables: $N_t, N_{D,t}, N_{V,t}, N_{H,t}, N_{E,t}, \tilde{d}_t, \tilde{d}_{D,t}, \tilde{d}_{V,t}, \tilde{d}_{H,t}, \tilde{z}_{D,t}, \tilde{z}_{V,t}, \tilde{z}_{H,t}, \tilde{v}_t, r_t, w_t$ and C_t . As the Southern firms do not offshore to the high-wage North, the Southern economy is described by only 11 equations in 11 endogenous variables: There are no Southern counterparts for $N_t, N_{V,t}, \tilde{d}_{V,t}, \tilde{z}_{D,t}$ and $\tilde{z}_{V,t}$. In particular, the average labor productivity of the representative domestic Southern firm (\tilde{z}_D^*) is constant over time. Variables $N_{D,t}, r_t, N_t^*$ and r_t^* are predetermined.

1.A.2 Offshoring with Financial Integration

I allow for trade in international bonds in an extended version of the model with endogenous offshoring. Following GM2005, I assume that: (1) International asset markets are incomplete, as households in each country issue risk-free bonds denominated in their own currency. (2) Nominal returns are indexed to inflation in each economy, so that each type of bonds provides a real return denominated in units of that country's consumption basket. (3) I introduce quadratic costs of adjustment for bond holdings, a tool which allows to pin down the steady state and ensure stationarity for the net foreign assets in the presence of temporary shocks.

The infinitely-lived representative household in the North maximizes the inter-temporal utility subject to the constraint:

$$\begin{aligned}
& (\tilde{d}_t + \tilde{v}_t)N_t x_t + w_t L + (1 + r_t) B_{h,t} + (1 + r_t^*) Q_t B_{f,t} + T_t \\
& \geq C_t + \tilde{v}_t (N_t + N_{E,t}) x_{t+1} + B_{h,t+1} + \frac{\pi}{2} (B_{h,t+1})^2 + Q_t B_{f,t+1} + \frac{\pi}{2} Q_t (B_{f,t+1})^2,
\end{aligned} \tag{1.39}$$

where r_t and r_t^* are the rates of return of the North and South-specific bonds; $(1+r_t)B_{h,t}$ and $(1+r_t^*)Q_t B_{f,t}$ denote the principal and interest income from each type of bonds; $\frac{\pi}{2}(B_{h,t+1})^2$ and $\frac{\pi}{2}Q_t(B_{f,t+1})^2$ are the adjustment costs for each type of bond holdings; T_t is the fee rebate. Setting $\pi = 0.0025$, I add the two Euler equations for bonds to the baseline model:

$$1 + \pi B_{h,t+1} = \beta(1 + r_{t+1})E_t \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma}, \quad (1.40)$$

$$1 + \pi B_{f,t+1} = \beta(1 + r_{t+1}^*)E_t \frac{Q_{t+1}}{Q_t} \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma}. \quad (1.41)$$

The budget constraint of the Southern household is similar, and the corresponding Euler equations for bonds are:

$$1 + \pi B_{h,t+1}^* = \beta^*(1 + r_{t+1})E_t \frac{Q_t}{Q_{t+1}} \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\gamma}, \quad (1.42)$$

$$1 + \pi B_{f,t+1}^* = \beta^*(1 + r_{t+1}^*)E_t \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\gamma}. \quad (1.43)$$

The market clearing conditions for bonds are:

$$B_{h,t+1} + B_{h,t+1}^* = 0, \quad (1.44)$$

$$B_{f,t+1} + B_{f,t+1}^* = 0. \quad (1.45)$$

Thus, financial integration through trade in bonds adds 4 new variables ($B_{h,t}$, $B_{f,t}$, $B_{h,t}^*$, $B_{f,t}^*$) and 6 new equations (1.40, 1.41, 1.42, 1.43, 1.44 and 1.45) while removing the original two Euler equations from the baseline model with financial autarky. Trade in bonds also involves changes in the aggregate accounting equations and in the balanced current account

condition. I re-write the expressions for aggregate accounting in the North and the South as:

$$C_t + N_{E,t}\tilde{v}_t + B_{h,t+1} + Q_t B_{f,t+1} = w_t L + N_t \tilde{d}_t + (1 + r_t) B_{h,t} + (1 + r_t^*) Q_t B_{f,t}, \quad (1.46)$$

$$C_t^* + N_{E,t}^* \tilde{v}_t^* + Q_t^{-1} B_{h,t+1}^* + B_{f,t+1}^* = w_t^* L^* + N_{D,t}^* \tilde{d}_t^* + (1 + r_t) Q_t^{-1} B_{h,t}^* + (1 + r_t^*) B_{f,t}^*. \quad (1.47)$$

I also replace the balanced current account condition from the model with financial autarky with the expression for the balance of international payments:

$$TB_t + \underbrace{N_{V,t}\tilde{d}_{V,t}}_{\text{Repatriated profits}} + \underbrace{r_t B_{h,t} + r_t^* Q_t B_{f,t}}_{\text{Income from bonds}} = \underbrace{(B_{h,t+1} - B_{h,t}) - Q_t (B_{f,t+1} - B_{f,t})}_{\text{Change in bond holdings}} \quad (1.48)$$

which shows that the current account balance (trade balance plus repatriated profits of foreign affiliates plus investment income) must equal the negative of the financial account balance (the change in bond holdings).

1.A.3 Employment Dynamics

Theoretical measures of sectoral employment In this section I study the effect of offshoring on employment in both the North and the South. To this end, I focus on the offshoring sector in the Southern economy in addition to the three employment sectors in each economy (entry, domestic and exporting) described in GM2005.⁴⁶ The representative

⁴⁶In the North, the representative firm serving the domestic labor hires labor for production ($\tilde{l}_{D,t} = \frac{\theta-1}{w_t} \tilde{d}_{D,t}$ units of labor). The representative firm serving the foreign market through exports hires labor both for production ($\tilde{l}_{H,t} = \tilde{d}_{H,t} \frac{\theta-1}{w_t} + f_H \frac{\theta-1}{Z_t}$) and for covering the fixed cost of exporting ($\frac{f_H}{Z_t}$ units of labor). In addition, the new firms hire labor to satisfy the entry cost requirements ($\frac{f_E}{Z_t}$ units of labor per new entrant every period). Thus, the amount of labor hired by each of the three sectors in the North (entry, domestic,

Northern offshoring firm hires Southern labor both for covering the fixed cost of offshoring ($\frac{f_V}{Z_t^*}$ units of Southern labor every period) and for production ($\tilde{l}_{V,t}^* = \tilde{d}_{V,t} \frac{\theta-1}{w_t^* Q_t} + f_V \frac{\theta-1}{Z_t^*}$).

Thus, I write the total employment in the offshoring sector as:

$$L_{V,t}^* = N_{V,t} \left(\tilde{l}_{V,t}^* + \frac{f_V}{Z_t^*} \right). \quad (1.49)$$

The log-linearized expressions for total employment in each economy are:

$$\hat{L}_t = \frac{L_E}{L} \hat{L}_{E,t} + \frac{L_D}{L} \hat{L}_{D,t} + \frac{L_H}{L} \hat{L}_{H,t}, \quad (1.50)$$

$$\hat{L}_t^* = \frac{L_V^*}{L^*} \hat{L}_{V,t}^* + \frac{L_E^*}{L^*} \hat{L}_{E,t}^* + \frac{L_D^*}{L^*} \hat{L}_{D,t}^* + \frac{L_H^*}{L^*} \hat{L}_{H,t}^*, \quad (1.51)$$

where the calibration implies that the steady state shares of employment in the North are 22, 53 and 25 percent for the entry, domestic and exporting sectors. In the South, they are 15, 48 and 15 percent respectively, plus the remaining 22 percent in the offshoring sector.

Impulse responses for a productivity increase in the North Figure A.1 illustrates the employment dynamics in the offshoring model in response to a positive productivity shock in the North, when productivity follows the autoregressive univariate process $\log Z_{t+1} = \rho \log Z_t + u_t$ with persistence parameter $\rho = 0.9$. In order to analyze the employment dynamics, I add elastic labor supply to the framework with offshoring under financial autarky.⁴⁷

and export) every period is $L_{E,t} = N_{E,t} \frac{f_E}{Z_t}$, $L_{D,t} = N_{D,t} \tilde{l}_{D,t}$ and $L_{H,t} = N_{H,t} \left(\tilde{l}_{H,t} + \frac{f_H}{Z_t} \right)$, respectively.

⁴⁷The representative household aiming to maximize the expected inter-temporal utility $\max_{\{B_t, x_t, L_t\}} \left[E_t \sum_{s=t}^{\infty} \beta^{s-t} \left(\ln C_s - \chi \frac{L_s^{1+\psi}}{1+\psi} \right) \right]$ consumes and supplies L_t working hours elastically in a competitive labor market subject to the budget constraint $B_{t+1} + \tilde{v}_t (N_t + N_{E,t}) x_{t+1} + C_t =$

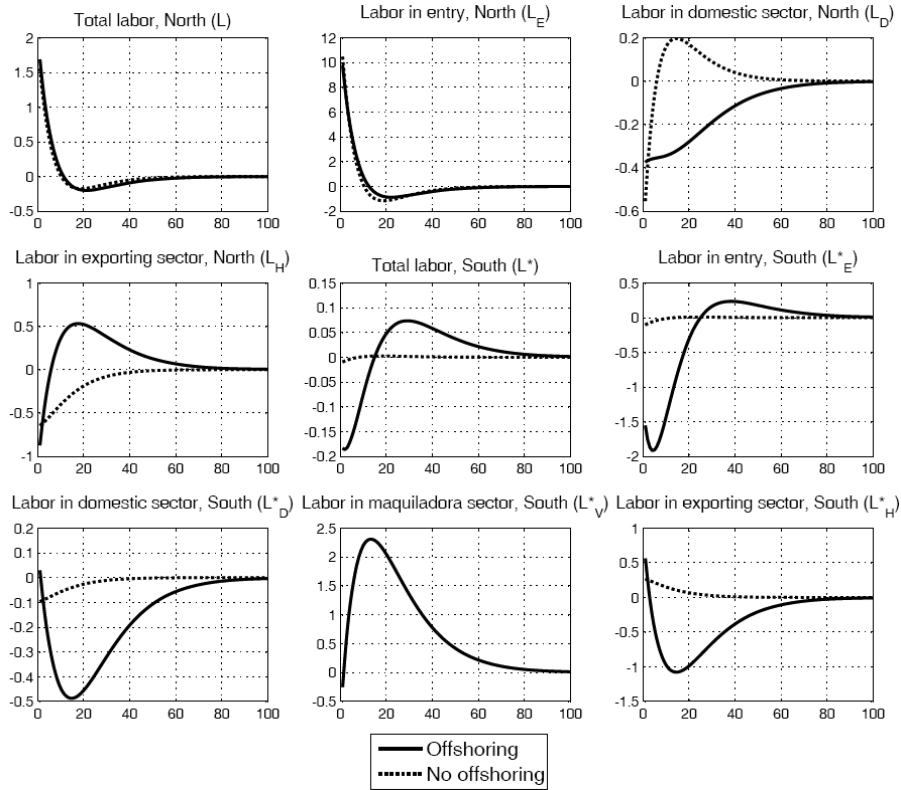


Figure A.1. Employment dynamics,

impulse responses to a transitory 1 percent productivity shock in North

In the North, on impact, employment rises in the entry sector and declines in the domestic and exporting sectors. Thus, the reallocation of labor across sectors supports the

$(1 + r_t)B_t + (\tilde{d}_t + \tilde{v}_t)N_t x_t + w_t L_t$, where $\chi > 0$ is the weight of disutility from labor in the period utility function, and $\psi \geq 0$ is the Frisch elasticity of labor supply to wages and the inter-temporal elasticity of substitution in labor supply. Following King, Plosser and Rebello (1988) and the discussions in Campbell (1994) and Bilbie et al. (2006), I use log utility for consumption (which is equivalent to setting $\gamma = 1$ in the baseline model) in order to obtain constant steady state labor supply in a model in which utility is additively separable over consumption and hours. I incorporate the usual first order conditions with respect to hours worked into the model, $\chi(L_t)^{\frac{1}{\psi}} = w_t C_t^{-1}$ and $\chi^*(L_t)^{\frac{1}{\psi^*}} = w_t^* C_t^{*-1}$. Using the baseline model calibration, I set the weight parameter $\chi = 0.9188$ and $\chi^* = 0.9458$, so that the steady-state level of hours worked is equal to unit, $\bar{L} = \left\{ \frac{1}{\chi} \frac{\bar{w}}{\bar{C}} \right\}^{\psi} = 1$. The wage elasticity of labor supply in North and South is $\psi = 3$.

creation of new product varieties following the productivity improvement in the Northern economy, both in the model with offshoring and in the model with exports only.

Important differences in employment dynamics across the two models become visible in the medium run. First, as the option to produce offshore improves the average profitability of prospective entrants, firm entry is more persistent and employment in the entry sector declines by less in the model with offshoring than in the model with exports only. Second, an aggregate productivity increase stimulates employment in the Northern exporting sector in the presence of offshoring (and reduces it without), as the dampened appreciation of the terms of labor enhances the competitiveness of the Northern exports relative to the model with exports only. Third, offshoring reduces employment in the Northern domestic sector, partly due to the relocation of production to the South, and partly due to the within-country reallocation of employment towards the entry and exporting sectors in the North. Overall, the employment loss in the North caused by offshoring is partially offset by the employment gains generated by enhanced product creation and export competitiveness in the North.

In the Southern economy, the increase in employment in the offshoring sector offsets the loss in the domestic and exporting sectors, as well as the loss in the entry sector in the short run. The result is in line with the empirical evidence that, due to the crowding out of domestic investment, most of the new jobs in Mexico's manufacturing (96 percent) during 1994-2002 were in the maquiladora sector (Gallagher and Zarsky, 2007, Chapter 2).

1.A.4 Welfare Analysis: Offshore Production and Trade Costs

In this section I analyze the welfare effect of a sudden and permanent decrease in the iceberg trade cost that affects offshoring from $\tau_0 = 1.3$ to $\tau_1 = 1.2$, which occurs in addition to the

stochastic transitory shocks to aggregate productivity. To this end, I take a second order approximation around the steady state, and assume that aggregate productivity follows the bivariate autoregressive process described in expression (1.38), with the persistence, spillover and variance-covariance matrix of shocks from Backus, Kehoe, and Kydland (1992, 1994).

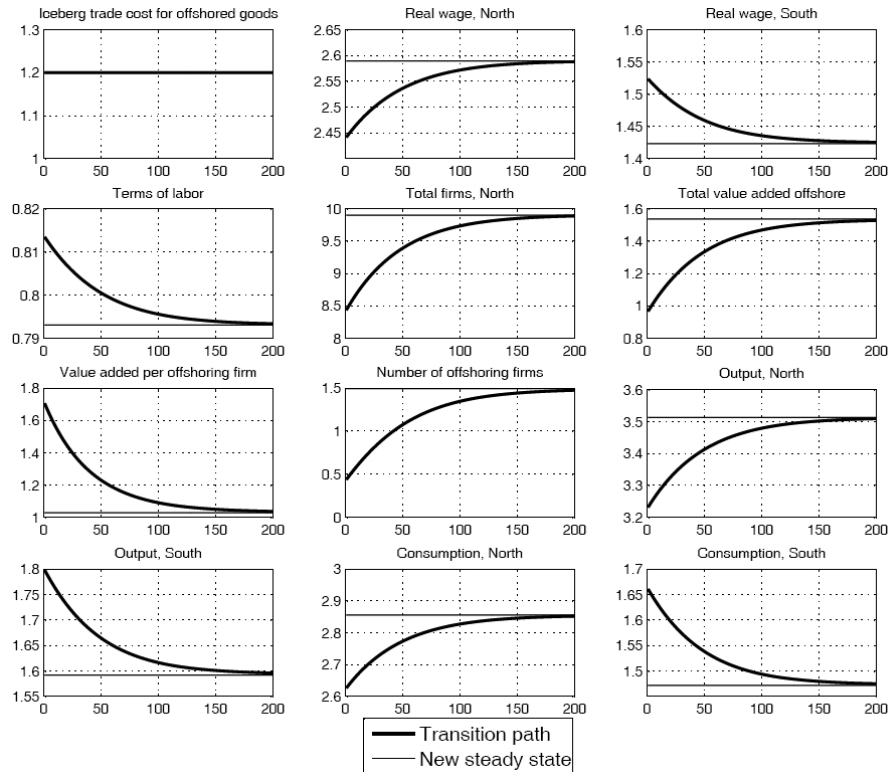


Figure A.2. Transition paths to new steady states, following a permanent decrease

in the iceberg trade cost of offshoring (from $\tau_0 = 1.3$ to $\tau_1 = 1.2$)

Figure A.2 plots the transition paths to the new steady state for key variables of the model. The lower trade cost associated with offshoring increases profitability and hence stimulates firm entry in the North. In turn, the total number of Northern firms, the real wage, output and consumption converge to relatively higher steady state levels, an outcome

which is welfare-enhancing for the Northern economy. The total value added offshore and the number of offshoring firms also converge to higher steady state levels. In the Southern economy, the real wage, consumption and output decrease to lower steady state values due to the crowding out of domestic entry by offshoring.

In order to compute the consumption-equivalent gain that the Northern economy obtains from the decline in the fixed cost of offshoring, I compare the level of welfare that the Northern household holds in the initial steady state (V_0) with the level of welfare that it holds as of period t' when the decrease in the trade cost takes place ($V_{t'}$):

$$V_0 = \frac{1}{1-\beta} U(\bar{C}_{\tau_0=1.3}) \quad \text{and} \quad V_{t'} = E_{t'} \sum_{v=t'}^{\infty} \beta^v U(\bar{C}_v). \quad (1.52)$$

The welfare level of period t' takes into account the discounted stream of utilities that the Northern household achieves at all future periods during the transition path to the new steady state. Then I define the constants \bar{C}_0 and \bar{C}_1 to denote the permanent streams of consumption necessary to generate the welfare values V_0 and $V_{t'}$:

$$V_0 = \frac{1}{1-\beta} \frac{\bar{C}_0^{1-\gamma}}{1-\gamma} \quad \text{and} \quad V_{t'} = \frac{1}{1-\beta} \frac{\bar{C}_1^{1-\gamma}}{1-\gamma}, \quad (1.53)$$

and compute the consumption-equivalent welfare gain ($\lambda > 0$) or loss ($\lambda < 0$) that corresponds to the permanent decrease of the iceberg trade cost for offshored goods as:

$$\lambda = \left(\frac{\bar{C}_1}{\bar{C}_0} - 1 \right) \times 100. \quad (1.54)$$

Figure A.3 (continuous line) plots the consumption-equivalent welfare gain measured as

a percentage increase in steady-state consumption (on the vertical axis) associated with the permanent decrease in the trade cost for offshored goods; I allow the elasticity of substitution between domestic and offshored varieties (on the horizontal axis) to vary over $\theta \in [3.1, 3.9]$. The results show that the Northern economy obtains a welfare gain that exceeds the equivalent of 5 percent of initial consumption for the entire range of elasticity values. Moreover, the gain increases with the degree of complementarity between the domestic and offshored varieties.

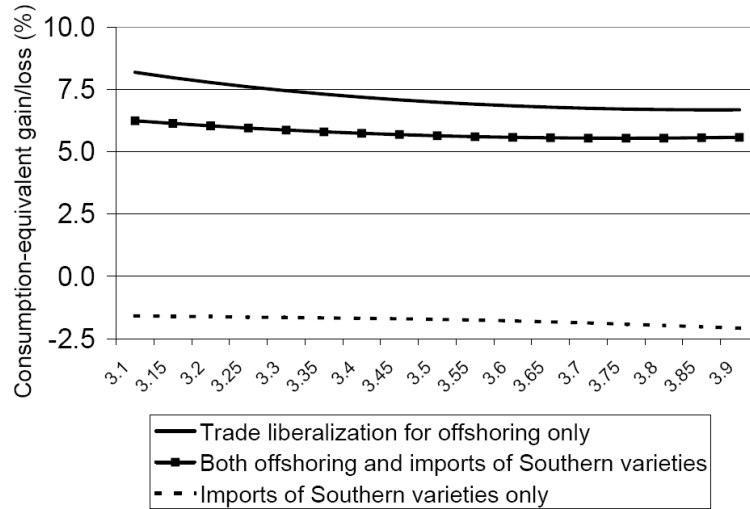


Figure A.3. Consumption-equivalent welfare gain/loss, following a permanent decrease in the iceberg trade cost of offshoring (from $\tau_0 = 1.3$ to $\tau_1 = 1.2$)

1.A.5 Asymmetric Firm Entry Costs

The World Bank’s *Doing Business* report outlines the large variation in the regulation of starting a business across countries at different levels of economic development (Table A.2). For instance, the monetary cost is 3.3 times higher in Mexico than in the U.S. or Canada;

it is 6.2 times higher in Hungary than in the U.K.

Table A.2. Firm entry costs, selected economies

Economy	Procedures (number)	Duration (days)	Monetary Cost (USD)	Relative Cost (U.S.=1.0)
U.S.	6	6	314.79	1.0
Canada	2	3	325.53	1.0
Mexico	8	27	1,046.71	3.3
Germany	9	18	2,087.34	6.6
U.K.	6	13	321.44	1.0
France	5	7	402.05	1.3
Poland	10	31	1,736.28	5.5
Czech Republic	10	17	1,344.08	4.3
Hungary	6	16	1,938.15	6.2

(Source: World Bank, *Doing Business* Report, 2007)

1.A.6 Solution for the Asymmetric Steady State ($TOL < 1$)

In this section I provide the steady state solution for the model of offshoring in the presence of cross-country differences in the cost of effective labor ($TOL < 1$). To this end, I use an integrated framework that nests both the baseline model of offshoring (for calibration $\alpha = 0, \eta = 1$) and the benchmark model with exports only and no offshoring in GM2005 (for $\alpha = 1, \eta = 1$), as described in footnotes 15 and 23 above.

I obtain a numerical solution for the unique steady state using a non-linear system of

12 equations in 12 unknowns, listed below. The unknowns are the steady state values of: z_V (the offshoring cutoff productivity), z_H (the exporting cutoff productivity in North), TOL , $\frac{C}{C^*Q}$, Q , $\frac{\tilde{d}_D}{w}$, $\frac{\tilde{d}_V}{w}$, $\frac{\tilde{d}_H}{w}$, z_H^* (the exporting cutoff productivity in South), $\tilde{\rho}_H$, $\tilde{\rho}_H^*$, and $\frac{N}{N^*}$. Subsequently, I use the numerical solution for the initial 12 variables to compute the steady state values of the remaining variables of the model. A technical appendix providing their complete derivation is available upon request.

I use the following pricing and profit formulas (in which $Z = Z^* = 1$) in order to derive the steady state solution:

Table A.3.1. Average Prices

Domestic production, North	$\tilde{\rho}_D = \frac{\theta}{\theta-1} \frac{w_t}{\tilde{z}_D}$
Domestic production, South	$\tilde{\rho}_D^* = \frac{\theta}{\theta-1} \frac{w_t^*}{\tilde{z}_D^*}$
Offshore production (vertical FDI, $\alpha = 0$)	$\tilde{\rho}_V = \frac{\theta}{\theta-1} \frac{w}{\tilde{z}_V} (\tau TOL)^{1-\alpha}$
Exports ($\eta = 1$) or horizontal FDI ($\eta = 0$), North	$\tilde{\rho}_H = \frac{\theta}{\theta-1} \frac{\tau^{\eta} w Q^{-1}}{\tilde{z}_H} TOL^{1-\eta}$
Exports ($\eta^* = 1$) or horizontal FDI ($\eta^* = 0$), South	$\tilde{\rho}_H^* = \frac{\theta}{\theta-1} \frac{\tau^{\eta^*} w^* Q}{\tilde{z}_H^*} \left(\frac{1}{TOL}\right)^{1-\eta^*}$

Table A.3.2. Average Profits

Domestic production, North	$\tilde{d}_{D,t} = \frac{1}{\theta} (\tilde{\rho}_{D,t})^{1-\theta} C_t$
Domestic production, South	$\tilde{d}_{D,t}^* = \frac{1}{\theta} (\tilde{\rho}_{D,t}^*)^{1-\theta} C_t^*$
Offshore production (vertical FDI, $\alpha = 0$)	$\tilde{d}_{V,t} = \frac{1}{\theta} (\tilde{\rho}_{V,t})^{1-\theta} C_t - f_V w TOL^{1-\alpha}$
Exports ($\eta = 1$) or horiz. FDI ($\eta = 0$), North	$\tilde{d}_{H,t} = \frac{1}{\theta} (\tilde{\rho}_{H,t})^{1-\theta} C_t^* Q_t - f_H w TOL^{1-\eta}$
Exports ($\eta^* = 1$) or horiz. FDI ($\eta^* = 0$), South	$\tilde{d}_{H,t}^* = \frac{1}{\theta} (\tilde{\rho}_{H,t}^*)^{1-\theta} C_t Q_t^{-1} - f_H^* w^* \left(\frac{w_t^*}{Z_t^*}\right) \left(\frac{1}{TOL}\right)^{1-\eta^*}$

In addition, using that $v = \frac{\beta(1-\delta)}{1-\beta(1-\delta)}d$, $N_E = \frac{\delta}{1-\delta}N$, and $v = f_e w$ in the expression for total profits in the Northern economy, the first equation in the system is:

$$\frac{1 - \beta(1 - \delta)}{\beta(1 - \delta)} f_E = \frac{N_D}{N} \frac{\tilde{d}_D}{w} + \frac{N_V}{N} \frac{\tilde{d}_V}{w} + \frac{N_H}{N} \frac{\tilde{d}_H}{w}, \quad (1.55)$$

where $\frac{N_H}{N} = \left(\frac{1}{z_H}\right)^k$, $\frac{N_D}{N} = 1 - \left(\frac{1}{z_H}\right)^k$, $\frac{N_V}{N} = \left(\frac{1}{z_V}\right)^k$.

Next, the profit formulas for the Northern economy imply:

$$\frac{\tilde{d}_D}{w} = \frac{k}{k - (\theta - 1)} f_H TOL^{\theta(1-\eta)} \frac{C}{C^* Q} Q^{1-\theta} \tau^{*(\theta-1)\eta} \left(\frac{z_V}{z_H}\right)^{\theta-1} \frac{z_V^{k-(\theta-1)} - 1}{z_V^k - 1}, \quad (1.56)$$

$$\frac{\tilde{d}_V}{w} = \frac{k}{k - (\theta - 1)} f_H TOL^{1-\alpha+\theta(\alpha-\eta)} \frac{C}{C^* Q} Q^{1-\theta} \left(\frac{z_V}{z_H}\right)^{\theta-1} \frac{\tau^{*(\theta-1)\eta}}{\tau^{(1-\alpha)(\theta-1)}} - f_V TOL^{1-\alpha}, \quad (1.57)$$

$$\frac{\tilde{d}_H}{w} = \frac{(\theta - 1)}{k - (\theta - 1)} f_H w TOL^{1-\eta}, \quad (1.58)$$

$$\frac{\tilde{d}_V}{w} = \frac{z_V^k - 1}{z_V^{k-(\theta-1)} - 1} \frac{\tilde{d}_D}{w} + \frac{(\theta - 1)}{k - (\theta - 1)} f_V w TOL^{1-\alpha}. \quad (1.59)$$

The expression for total profits in the Southern economy implies:

$$\begin{aligned} \frac{1 - \beta^*(1 - \delta^*)}{\beta^*(1 - \delta^*)} f_E^* &= \frac{k}{k - (\theta - 1)} f_H^* TOL^{\theta(\eta^*-1)} \tau^{\eta^*(\theta-1)} Q^{\theta-1} z_H^{*1-\theta} \frac{C^* Q}{C} + \\ &+ \frac{\theta - 1}{k - (\theta - 1)} \left(\frac{1}{z_H^*}\right)^k f_H^* TOL^{\eta^*-1}, \end{aligned} \quad (1.60)$$

Next, the consumption ratio adjusted for the real exchange rate is:

$$\frac{C}{C^* Q} = \frac{f_H^*}{f_H} TOL^{\theta(\eta+\eta^*-1)} Q^{\theta-1} \left(\frac{z_H \tau^{\eta^*}}{z_H^* \tau^{*\eta}}\right)^{\theta-1}. \quad (1.61)$$

Using the balanced current account condition, I obtain:

$$\begin{aligned}
(1 - \alpha) z_V^{-k} TOL^{-\alpha} & \left[\frac{(\theta - 1) k}{k - (\theta - 1)} f_H^* \left(\frac{z_V}{z_H^*} \right)^{\theta-1} \frac{TOL^{\theta(\alpha+\eta^*-1)}}{\tau^{(\theta-1)(1-\alpha-\eta^*)}} + f_V \right] \\
& = \Lambda \frac{f_H}{z_H^k} \left(\frac{N}{N_D^*} \right)^{-1} TOL^{-\eta} - \Lambda^* \frac{f_H^*}{z_H^{*k}} \left(\frac{N}{N_D^*} \right)^{-1} TOL^{\eta^*-1},
\end{aligned} \tag{1.62}$$

where $\Lambda = \left(\eta + \frac{(1-\eta)}{\theta} \right) \frac{k\theta}{k-(\theta-1)} - (1-\eta)$ and $\Lambda^* = \left(\eta^* + \frac{(1-\eta^*)}{\theta} \right) \frac{k\theta}{k-(\theta-1)} - (1-\eta^*)$.

The expression for the real exchange rate in steady state is:

$$Q^{1-\theta} = \frac{TOL^{1-\theta} + (\tau^* \eta TOL^{1-\eta})^{1-\theta} z_H^{\theta-1-k} \frac{N}{N_D^*}}{\left(1 - z_V^{-k} \right) z_V^{\theta-1} \frac{z_V^{k-(\theta-1)} - 1}{z_V^k - 1} \frac{N}{N_D^*} + z_V^{\theta-1-k} \frac{N}{N_D^*} (\tau TOL)^{(1-\alpha)(1-\theta)} + z_H^{*\theta-1-k} \frac{N}{N_D^*} (\tau TOL)^{\eta^*(1-\theta)}} \tag{1.63}$$

The remaining equations are:

$$\frac{\theta k}{k - (\theta - 1)} f_H \frac{\tilde{\rho}_H^{\theta-1}}{TOL^\eta} = 1 + \frac{1 - \beta^*}{\beta^* (1 - \delta^*)} f_E^* \frac{\tilde{\rho}_H^{\theta-1}}{\Xi_t}, \tag{1.64}$$

$$\frac{\theta k}{k - (\theta - 1)} f_H^* TOL^{\eta^*} \tilde{\rho}_H^{*\theta-1} = 1 + \frac{1 - \beta}{\beta (1 - \delta)} f_E \frac{\tilde{\rho}_H^{*\theta-1}}{\Omega_t}, \tag{1.65}$$

$$\frac{N}{N_D^*} \left(\frac{\tilde{\rho}_H}{\tilde{\rho}_H^*} \right)^{\theta-1} = \frac{\Xi_t}{\Omega_t}, \tag{1.66}$$

where:

$$\Xi_t = \left[\frac{1}{z_H} \left(\frac{\tau^*}{TOL} \right)^\eta \right]^{\theta-1} + z_H^{-k} \frac{N}{N_D^*}, \tag{1.67}$$

$$\begin{aligned}
\Omega_t & = \left(1 - z_V^{-k} \right) \left(\frac{z_V}{z_H^*} \right)^{\theta-1} \frac{z_V^{k-(\theta-1)} - 1}{z_V^k - 1} (\tau TOL)^{\eta^*(\theta-1)} \\
& \quad + z_V^{-k} \left[\frac{z_V}{z_H^*} (\tau TOL)^{\eta^*+\alpha-1} \right]^{\theta-1} + z_H^{*-k} \left(\frac{N}{N_D^*} \right)^{-1}.
\end{aligned} \tag{1.68}$$

1.A.7 Demand Functions and the Welfare-Based Price Index

The Northern representative household minimizes the total expenditure associated with the consumption basket C_t , which includes final good varieties produced by the Northern firms domestically ($y_{D,t}$), offshore ($y_{V,t}$), as well as final good varieties produced by Southern firms ($y_{H,t}^*$):

$$\min_{\{y_{D,t}(z), y_{V,t}(z), y_{H,t}^*(z)\}} P_t C_t = \underbrace{\int_{z_{\min}}^{z_{V,t}} p_{D,t}(z) y_{D,t}(z) dz}_{\text{Produced domestically}} + \underbrace{\int_{z_{V,t}}^{\infty} p_{V,t}(z) y_{V,t}(z) dz}_{\text{Produced offshore}} + \underbrace{\int_{z_{H,t}^*}^{\infty} p_{H,t}^*(z) y_{H,t}^*(z) dz}_{\text{Produced by Southern firms}}, \quad (1.69)$$

subject to $C_t = \left[\int_{z_{\min}}^{z_{V,t}} y_{D,t}(z)^{\frac{\theta-1}{\theta}} dz + \int_{z_{V,t}}^{\infty} y_{V,t}(z)^{\frac{\theta-1}{\theta}} dz + \int_{z_{H,t}^*}^{\infty} y_{H,t}^*(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}$. The first-order conditions with respect to $y_{D,t}(z)$, $y_{V,t}(z)$ and $y_{H,t}^*(z)$ imply:

$$p_{D,t}(z) = \lambda_t C_t^{\frac{1}{\theta}} y_{D,t}(z)^{-\frac{1}{\theta}}, \quad p_{V,t}(z) = \lambda_t C_t^{\frac{1}{\theta}} y_{V,t}(z)^{-\frac{1}{\theta}} \quad \text{and} \quad p_{H,t}^*(z) = \lambda_t C_t^{\frac{1}{\theta}} y_{H,t}^*(z)^{-\frac{1}{\theta}}, \quad (1.70)$$

which I use to re-write the total expenditure amount:

$$P_t C_t = \int_{z_{\min}}^{z_{V,t}} p_{D,t}(z) y_{D,t}(z) dz + \int_{z_{V,t}}^{\infty} p_{V,t}(z) y_{V,t}(z) dz + \int_{z_{H,t}^*}^{\infty} p_{H,t}(z) y_{H,t}^*(z) dz = \quad (1.71)$$

$$= \lambda_t C_t^{\frac{1}{\theta}} \underbrace{\left[\int_{z_{\min}}^{z_{V,t}} y_{D,t}(z)^{\frac{\theta-1}{\theta}} dz + \int_{z_{V,t}}^{\infty} y_{V,t}(z)^{\frac{\theta-1}{\theta}} dz + \int_{z_{H,t}^*}^{\infty} y_{H,t}^*(z)^{\frac{\theta-1}{\theta}} dz \right]}_{C_t^{\frac{\theta-1}{\theta}}} = \lambda_t C_t. \quad (1.72)$$

Next I insert the resulting identity $\lambda_t = P_t$ and the demand functions $y_{D,t}(z) = (p_{D,t}(z)/P_t)^{-\theta} C_t$, $y_{V,t}(z) = (p_{V,t}(z)/P_t)^{-\theta} C_t$, $y_{H,t}^*(z) = (p_{H,t}^*(z)/P_t)^{-\theta} C_t$ into the expres-

sion for total expenditure, $P_t C_t = \int_{z_{\min}}^{z_{V,t}} p_{D,t}(z) y_{D,t}(z) dz + \int_{z_{V,t}}^{\infty} p_{V,t}(z) y_{V,t}(z) dz + \int_{z_{H,t}^*}^{\infty} p_{H,t}^*(z) y_{H,t}^*(z) dz$,

in order to derive the price index:

$$P_t = \left[\int_{z_{\min}}^{z_{V,t}} p_{D,t}(z)^{1-\theta} dz + \int_{z_{V,t}}^{\infty} p_{V,t}(z)^{1-\theta} dz + \int_{z_{H,t}^*}^{\infty} p_{H,t}(z)^{1-\theta} dz \right]^{\frac{1}{1-\theta}}. \quad (1.73)$$

Throughout the model I use the consumption basket as the numeraire good in each economy. Thus, the real prices of final good varieties expressed in units of the Northern consumption basket are:

$$\rho_{D,t}(z) \equiv \frac{p_{D,t}(z)}{P_t}, \quad \rho_{V,t}(z) \equiv \frac{p_{V,t}(z)}{P_t} \quad \text{and} \quad \rho_{H,t}^*(z) \equiv \frac{p_{H,t}^*(z)}{P_t}, \quad (1.74)$$

and the demand functions for final good varieties become:

$$y_{D,t}(z) = \rho_{D,t}(z)^{-\theta} C_t, \quad y_{V,t}(z) = \rho_{V,t}(z)^{-\theta} C_t, \quad \text{and} \quad y_{H,t}^*(z) = \rho_{H,t}^*(z)^{-\theta} C_t. \quad (1.75)$$

1.A.8 Profit Maximization with Domestic and Offshore Production

Northern firms producing domestically Firms set optimal prices by solving the profit maximization problem:

$$\max_{\{\rho_{D,t}(z)\}} \rho_{D,t}(z) y_{D,t}(z) - \frac{w_t}{Z_t z} y_{D,t}(z). \quad (1.76)$$

Using the demand function $y_{D,t}(z) = \rho_{D,t}(z)^{-\theta} C_t$, price is equal to the marginal cost plus the markup:

$$y_{D,t}(z) + \rho_{D,t}(z) \frac{\partial y_{D,t}(z)}{\partial \rho_{D,t}(z)} - \frac{w_t}{Z_t z} \frac{\partial y_{D,t}(z)}{\partial \rho_{D,t}(z)} = 0 \Rightarrow \rho_{D,t}(z) = \frac{\theta}{\theta - 1} \frac{w_t}{Z_t z}. \quad (1.77)$$

Northern firms producing offshore The firm with idiosyncratic labor productivity z that produces final goods using a mix of domestic and offshore inputs solves the following profit maximizing problem:⁴⁸

$$\max_{\{\rho_{V,t}\}} \rho_{V,t}(z) y_{V,t}(z) - \left(\frac{w_t}{Z_t z} \right)^\alpha \left(\tau \frac{w_t^* Q_t}{Z_t^* z} \right)^{1-\alpha} y_{D,t}(z) - f_V \left(\frac{w_t}{Z_t} \right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*} \right)^{1-\alpha}. \quad (1.78)$$

Using the demand function $y_{V,t}(z) = \rho_{V,t}(z)^{-\theta} C_t$, the resulting price formula is:

$$\rho_{V,t}(z) = \frac{\theta}{\theta - 1} \left(\frac{w_t}{Z_t z} \right)^\alpha \left(\tau \frac{w_t^* Q_t}{Z_t^* z} \right)^{1-\alpha}. \quad (1.79)$$

Firms serving the foreign market The pricing formulas for firms originating in the North and the South, each serving the foreign market through either exports ($\eta = \eta^* = 1$) or horizontal FDI ($\eta = \eta^* = 0$), are obtained in a similar way:

$$\rho_{H,t}(z) = \frac{\theta}{\theta - 1} \left(\tau^* \frac{w_t Q_t^{-1}}{Z_t z} \right)^\eta \left(\frac{w_t^*}{Z_t^* z} \right)^{1-\eta} \quad \text{and} \quad \rho_{H,t}^*(z) = \frac{\theta}{\theta - 1} \left(\tau \frac{w_t^* Q_t}{Z_t^* z} \right)^{\eta^*} \left(\frac{w_t}{Z_t z} \right)^{1-\eta^*}. \quad (1.80)$$

⁴⁸The cost minimization problem in the broader framework of offshoring, $\min_{\{l_t, l_t^*\}} w_t l_t + \tau w_t^* Q_t l_t^*$ so that $y_{V,t}(z) = \left[\frac{Z_t z l_t}{\alpha} \right]^\alpha \left[\frac{Z_t^* z l_t^*}{1-\alpha} \right]^{1-\alpha}$, leads to the following expression for the marginal cost: $MC_t = \left(\frac{w_t}{Z_t z} \right)^\alpha \left(\frac{\tau w_t^* Q_t}{Z_t^* z} \right)^{1-\alpha}$.

1.A.9 Existence of Equilibrium for the Offshoring Productivity Cutoff

As discussed in the text, two conditions must hold every period in order to ensure existence of the equilibrium productivity cutoff $z_{V,t}$: (1) $d_{V,t}(z)$ must be steeper than $d_{D,t}(z)$; and (2) $z_{\min} < z_{V,t}$.

The first condition implies that the effective wage in the South must be low enough relative to the effective wage in the North ($TOL_t < 1$), so that the more productive Northern firms find it profitable to relocate production offshore despite the iceberg trade cost ($\tau > 1$):

$$\tau \frac{w_t^* Q_t}{Z_t^*} < \frac{w_t}{Z_t z} \iff \tau TOL_t < 1. \quad (1.81)$$

The second condition, $z_{\min} < z_{V,t}$, requires that:

$$\begin{aligned} \text{Slope}(d_{V,t}(z)) &< \frac{\Theta f_E \frac{w_t}{Z_t} + f_V \frac{w_t^* Q_t}{Z_t^*}}{z_{\min}^{\theta-1}}, \\ z_{\min}^{\theta-1} \frac{1}{\theta} \left(\frac{\theta}{\theta-1} \frac{w_t}{Z_t} \right)^{1-\theta} C_t &< \Theta f_E \frac{w_t}{Z_t} + f_V \frac{w_t^* Q_t}{Z_t^*}, \\ \frac{1}{\theta} \left(\frac{\theta}{\theta-1} \frac{w_t}{Z_t z_{\min}} \right)^{1-\theta} C_t &< \Theta f_E \frac{w_t}{Z_t} + f_V \frac{w_t^* Q_t}{Z_t^*}, \\ d_{D,t}(z_{\min}) &< \Theta f_E \frac{w_t}{Z_t} + f_V \frac{w_t^* Q_t}{Z_t^*}, \end{aligned} \quad (1.82)$$

where $\Theta = \frac{1-\beta(1-\delta)}{\beta(1-\delta)}$. The last inequality shows that the profit obtained by the firm with the minimum productivity z_{\min} from domestic production must be smaller than the sum of the per-period value of the sunk entry cost and the fixed cost of offshoring.

1.A.10 Average Firm-Specific Productivity Levels under the Pareto Distribution

Northern firms producing offshore

$$\begin{aligned}
\tilde{z}_{V,t} &= \left[\frac{1}{1 - G(z_{V,t})} \int_{z_{V,t}}^{\infty} z^{\theta-1} g(z) dz \right]^{\frac{1}{\theta-1}} = \\
&= \left[\left(\frac{z_{V,t}}{z_{\min}} \right)^k \int_{z_{V,t}}^{\infty} z^{\theta-1} \frac{k z_{\min}^k}{z^{k+1}} dz \right]^{\frac{1}{\theta-1}} = \\
&= \left[\left(\frac{z_{V,t}}{z_{\min}} \right)^k \frac{k z_{\min}^k}{k - (\theta - 1)} z_{V,t}^{\theta-1-k} \right]^{\frac{1}{\theta-1}} = \\
&= \nu z_{V,t}, \tag{1.83}
\end{aligned}$$

where $\nu \equiv \left[\frac{k}{k - (\theta - 1)} \right]^{\frac{1}{\theta-1}}$.

Northern firms producing domestically

$$\begin{aligned}
\tilde{z}_{D,t} &= \left[\frac{1}{G(z_{V,t})} \int_{z_{\min}}^{z_{V,t}} z^{\theta-1} g(z) dz \right]^{\frac{1}{\theta-1}} = \\
&= \left[\frac{z_{V,t}^k}{z_{V,t}^k - z_{\min}^k} \int_{z_{\min}}^{z_{V,t}} z^{\theta-1} \frac{k z_{\min}^k}{z^{k+1}} dz \right]^{\frac{1}{\theta-1}} = \\
&= \left[\frac{z_{V,t}^k}{z_{V,t}^k - z_{\min}^k} \frac{k z_{\min}^k}{(\theta - k - 1)} \left(z_{V,t}^{\theta-1-k} - z_{\min}^{\theta-1-k} \right) \right]^{\frac{1}{\theta-1}} = \\
&= \nu \left[\frac{(z_{\min} z_{V,t})^k}{z_{\min}^k - z_{V,t}^k} \left(\frac{1}{z_{V,t}^{k-(\theta-1)}} - \frac{1}{z_{\min}^{k-(\theta-1)}} \right) \right]^{\frac{1}{\theta-1}} = \\
&= \nu z_{\min} z_{V,t} \left[\frac{z_{\min}^{k-(\theta-1)} - z_{V,t}^{k-(\theta-1)}}{z_{V,t}^k - z_{\min}^k} \right]^{\frac{1}{\theta-1}}. \tag{1.84}
\end{aligned}$$

1.A.11 Average Profits: Domestic and Offshore Production

The average profit of the Northern firms producing domestically is:

$$\begin{aligned}
\tilde{d}_{D,t} &= d_{D,t}(\tilde{z}_{D,t}) = \frac{1}{\theta} \left[\frac{\theta}{\theta-1} \frac{w_t}{Z_t \tilde{z}_{D,t}} \right]^{1-\theta} C_t = \frac{1}{\theta} \left[\frac{\theta}{\theta-1} \frac{w_t}{Z_t} \right]^{1-\theta} C_t \tilde{z}_{D,t}^{\theta-1} = \\
&= \frac{1}{\theta} \left[\frac{\theta}{\theta-1} \frac{w_t}{Z_t} \right]^{1-\theta} C_t (\nu z_{\min} z_{V,t})^{\theta-1} \left[\frac{z_{V,t}^{k-(\theta-1)} - z_{\min}^{k-(\theta-1)}}{z_{V,t}^k - z_{\min}^k} \right] = \\
&= \underbrace{\frac{1}{\theta} \left[\frac{\theta}{\theta-1} \frac{w_t}{Z_t z_{V,t}} \right]^{1-\theta} C_t (\nu z_{\min})^{\theta-1}}_{d_{D,t}(z_{V,t})} \left[\frac{z_{V,t}^{k-(\theta-1)} - z_{\min}^{k-(\theta-1)}}{z_{V,t}^k - z_{\min}^k} \right] = \\
&= d_{D,t}(z_{V,t}) (\nu z_{\min})^{\theta-1} \left[\frac{z_{V,t}^{k-(\theta-1)} - z_{\min}^{k-(\theta-1)}}{z_{V,t}^k - z_{\min}^k} \right]. \tag{1.85}
\end{aligned}$$

The average profit of the Northern firms producing offshore through vertical FDI is:

$$\begin{aligned}
\tilde{d}_{V,t} &= d_{V,t}(\tilde{z}_{V,t}) = \frac{1}{\theta} \left[\tau \frac{\theta}{\theta-1} \frac{w_t^* Q_t}{Z_t^* \tilde{z}_{V,t}} \right]^{1-\theta} C_t - f_V \left(\frac{w_t}{Z_t} \right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*} \right)^{1-\alpha} = \\
&= \frac{1}{\theta} \left[\tau \frac{\theta}{\theta-1} \frac{w_t^* Q_t}{Z_t^*} \right]^{1-\theta} C_t \tilde{z}_{V,t}^{\theta-1} - f_V \left(\frac{w_t}{Z_t} \right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*} \right)^{1-\alpha} = \\
&= \underbrace{\left\{ \frac{1}{\theta} \left[\tau \frac{\theta}{\theta-1} \frac{w_t^* Q_t}{Z_t^* z_{V,t}} \right]^{1-\theta} C_t - f_V \left(\frac{w_t}{Z_t} \right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*} \right)^{1-\alpha} \right\}}_{d_{V,t}(z_{V,t})} \nu^{\theta-1} + \\
&+ (\nu^{\theta-1} - 1) f_V \left(\frac{w_t}{Z_t} \right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*} \right)^{1-\alpha} \\
&= d_{V,t}(z_{V,t}) \nu^{\theta-1} + \frac{\theta-1}{k-(\theta-1)} f_V \left(\frac{w_t}{Z_t} \right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*} \right)^{1-\alpha}. \tag{1.86}
\end{aligned}$$

The Northern firm with productivity equal to the cutoff $z_{V,t}$ is indifferent between locating production domestically or offshore. Thus, I use the equality of the corresponding profits at the productivity cutoff, i.e. $d_{D,t}(z_{V,t}) = d_{V,t}(z_{V,t})$, along with the expressions 1.85

and 1.86 above, to derive the link between the two average profits as:

$$\begin{aligned}
\tilde{d}_{V,t} &= \underbrace{\left(\frac{1}{\nu z_{\min}}\right)^{\theta-1} \left[\frac{z_{V,t}^{k-(\theta-1)} - z_{\min}^{k-(\theta-1)}}{z_{V,t}^k - z_{\min}^k}\right]^{-1}}_{=d_{D,t}(z_{V,t})} \tilde{d}_{D,t} \nu^{\theta-1} + \frac{\theta-1}{k-(\theta-1)} f_V \left(\frac{w_t}{Z_t}\right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*}\right)^{1-\alpha} = \\
&= z_{\min}^{1-\theta} \left[\frac{z_{V,t}^{k-(\theta-1)} - z_{\min}^{k-(\theta-1)}}{z_{V,t}^k - z_{\min}^k}\right]^{-1} \tilde{d}_{D,t} + \frac{\theta-1}{k-(\theta-1)} f_V \left(\frac{w_t}{Z_t}\right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*}\right)^{1-\alpha} = \\
&= \frac{k}{k-(\theta-1)} \left(\frac{z_{V,t}}{\tilde{z}_{D,t}}\right)^{\theta-1} \tilde{d}_{D,t} + \frac{\theta-1}{k-(\theta-1)} f_V \left(\frac{w_t}{Z_t}\right)^\alpha \left(\frac{w_t^* Q_t}{Z_t^*}\right)^{1-\alpha}. \tag{1.87}
\end{aligned}$$

1.A.12 Real Exchange Rate

Using the definition $\tilde{Q}_t^{1-\theta} = \left(\frac{N_{D,t} + N_{V,t} + N_{H,t}^*}{N_{D,t}^* + N_{H,t}^*}\right) Q_t^{1-\theta}$ and the notation $\tilde{N}_t \equiv N_{D,t} + N_{V,t} + N_{H,t}^*$, $\tilde{N}_t^* \equiv N_{D,t}^* + N_{H,t}^*$; I re-write the CPI-based real exchange rate as:

$$\begin{aligned}
\tilde{Q}_t^{1-\theta} &= \frac{\tilde{N}_t}{\tilde{N}_t^*} \frac{N_{D,t}^* (\tilde{\rho}_{D,t}^* P_t^* \varepsilon_t)^{1-\theta} + N_{H,t} (\tilde{\rho}_{H,t} P_t^* \varepsilon_t)^{1-\theta}}{N_{D,t} (\tilde{\rho}_{D,t} P_t)^{1-\theta} + N_{V,t} (\tilde{\rho}_{V,t} P_t)^{1-\theta} + N_{H,t}^* [\tilde{\rho}_{H,t}^* P_t]^1} = \\
&= \frac{\tilde{N}_t}{\tilde{N}_t^*} \frac{N_{D,t}^* \left(\frac{w_t^* P_t^* \varepsilon_t}{Z_t^* \tilde{z}_{D,t}^*}\right)^{1-\theta} + N_{H,t} \left[\left(\frac{\tau_t^*}{TOL_t}\right)^\eta \frac{w_t^* P_t^* \varepsilon_t}{Z_t^* \tilde{z}_{H,t}^*}\right]^{1-\theta}}{N_{D,t} \left(\frac{w_t P_t}{Z_t \tilde{z}_{D,t}}\right)^{1-\theta} + N_{V,t} \left[\frac{(\tau_t TOL_t)^{1-\alpha} w_t P_t}{Z_t \tilde{z}_{V,t}}\right]^{1-\theta} + N_{H,t}^* \left[\frac{(\tau_t TOL_t)^\eta w_t P_t}{Z_t \tilde{z}_{H,t}^*}\right]^{1-\theta}} = \\
&= \frac{\frac{N_{D,t}^*}{\tilde{N}_t^*} \left[\frac{TOL_t}{\tilde{z}_{D,t}^*}\right]^{1-\theta} + \frac{N_{H,t}}{\tilde{N}_t^*} \left[\frac{(\tau_t^*)^\eta TOL_t^{1-\eta}}{\tilde{z}_{H,t}^*}\right]^{1-\theta}}{\frac{N_{D,t}}{\tilde{N}_t} \left(\frac{1}{\tilde{z}_{D,t}}\right)^{1-\theta} + \frac{N_{V,t}}{\tilde{N}_t} \left[\frac{(\tau_t TOL_t)^{1-\alpha}}{\tilde{z}_{V,t}}\right]^{1-\theta} + \frac{N_{H,t}^*}{\tilde{N}_t} \left[\frac{(\tau_t TOL_t)^\eta}{\tilde{z}_{H,t}^*}\right]^{1-\theta}}. \tag{1.88}
\end{aligned}$$

In what follows I use the notation $s_D \equiv N_D \left(\frac{w}{Z \tilde{z}_D}\right)^{1-\theta} + N_V \left[\frac{w}{Z \tilde{z}_V} (\tau TOL)^{1-\alpha}\right]^{1-\theta}$ to denote the steady-state share of spending in the North on goods produced by the Northern firms both domestically and offshore. Expression $s_V \equiv N_V \left[\frac{w}{Z \tilde{z}_V} (\tau TOL)^{1-\alpha}\right]^{1-\theta}$ denotes the steady-state share of spending in the North on goods produced by the Northern firms offshore only. (Therefore, $s_V < s_D$.) Expression $s_D^* \equiv N_D^* \left(\frac{w^* Q}{Z^* \tilde{z}_D^*}\right)^{1-\theta}$ denotes the steady-

state share of spending in the South on goods produced by the Southern firms domestically. I also take into account the fact that the average productivity of the Southern firms producing domestically \widehat{z}_D^* is constant over time. Using all of the above, I log-linearize the CPI-based real exchange rate:

$$\begin{aligned}
(1-\theta)\widehat{Q}_t &= s_D^* \left[\widehat{N}_{D,t}^* - \widehat{N}_t + (1-\theta)\widehat{TOL}_t \right] + \\
&+ (1-s_D^*) \left[\widehat{N}_{H,t} - \widehat{N}_t + (1-\theta) \left(\eta\widehat{\tau}_t + (1-\eta)\widehat{TOL}_t - \widehat{z}_{H,t} \right) \right] - \\
&- (s_D - s_V) \left[\widehat{N}_{D,t} - \widehat{N}_t - (1-\theta)\widehat{z}_{D,t} \right] - \\
&- s_V \left[\widehat{N}_{V,t} - \widehat{N}_t + (1-\theta) \left((1-\alpha)(\widehat{\tau}_t + \widehat{TOL}_t) - \widehat{z}_{V,t} \right) \right] - \\
&- (1-s_D) \left[\widehat{N}_{H,t}^* - \widehat{N}_t + (1-\theta) \left(\eta^*(\widehat{\tau}_t + \widehat{TOL}_t) - \widehat{z}_{H,t}^* \right) \right]. \tag{1.89}
\end{aligned}$$

Setting $\eta = \eta^* = 1$ so that my model of offshoring nests the model with endogenous exports in GM2005, (i.e. in addition to offshoring taking place from North to South, firms in each economy serve the foreign markets through exports), the log-linearized expression for the CPI-based real exchange rate becomes:

$$\begin{aligned}
\widehat{Q}_t &= [s_D - (1-\alpha)s_V + s_D^* - 1]\widehat{TOL}_t + \\
&+ (s_D - s_V)\widehat{z}_{D,t} + s_V\widehat{z}_{V,t} - (1-\alpha)s_V\widehat{\tau}_t + \\
&+ (1-s_D) \left(\widehat{z}_{H,t}^* - \widehat{\tau}_t \right) - (1-s_D^*) \left(\widehat{z}_{H,t} - \widehat{\tau}_t^* \right) + \\
&+ \frac{1}{\theta-1} \left(s_V - \frac{N_V}{N} \right) \left(\widehat{N}_{V,t} - \widehat{N}_{H,t}^* \right) + \\
&+ \frac{1}{\theta-1} \left[\left(\frac{N_D^*}{N^*} - s_D^* \right) \left(\widehat{N}_{D,t}^* - \widehat{N}_{H,t} \right) - \left(\frac{N_D}{N} - (s_D - s_V) \right) \left(\widehat{N}_{D,t} - \widehat{N}_{H,t}^* \right) \right]. \tag{1.90}
\end{aligned}$$

Chapter 2

Offshore Production to Mexico: The Intensive and Extensive Margin Responses to U.S. Technology Shocks

*Essay, May 2009*¹

2.1 Introduction

In this paper I conduct an empirical investigation of the dynamics of offshore production undertaken by U.S. manufacturing firms that, motivated by fluctuations in the relative wage, relocate part of their activities to Mexico at business cycle frequency. The relocation of production operations (an activity which I refer to as "offshoring" in this paper) takes place either through fully-owned subsidiaries or through arm's length relationships with Mexican contractors. In addition to lower labor costs, offshoring is facilitated by Mexico's maquiladora program that offers a series of advantages to foreign investors.² Thus, plants in

¹*JEL classification:* F23, F41; *Keywords:* offshore production, intensive and extensive margins, business cycle dynamics, country-specific technology shocks, long-run identification restrictions, structural VAR, Mexico's maquiladora sector.

²The maquiladora program, established by Mexico in 1965 in order to address rising unemployment in the Northern border states, grants a series of advantages to the foreign investors, including full foreign ownership,

the maquiladora sector import production inputs (mostly from their U.S. parent and client firms), add value in the form of incorporated domestic materials and labor, and export the resulting output mostly to the U.S. market (Gruben, 2001).

I study the business cycle dynamics of offshore production in Mexico by breaking down the total maquiladora value added into two margins. I define the *intensive margin* of offshoring as the real value added per maquiladora plant. I use the *extensive margin* concept to refer to the number of maquiladora plants in Mexico. Using conditional correlations and impulse response estimates, I examine the timing and magnitude of responses of the two margins to U.S. permanent technology shocks. Thus, my study highlights the importance of each of the two margins of offshoring as separate transmission mechanisms of business cycle fluctuations from the U.S. to Mexico. This is in line with the existing literature reporting that fluctuations in the extensive margin (the number of plants) have a non-trivial effect on the Mexican economy: Bergin, Feenstra and Hanson (2008) show that more than one third of the adjustment in maquiladora's industry-level employment, and nearly half of the adjustment in maquiladora's total employment are due to fluctuations in the number of plants.

I start by outlining a set of *unconditional* correlations that describe the cyclical nature of offshoring from U.S. manufacturing to Mexico's maquiladora sector. I show that the total value added in Mexico is pro-cyclical with U.S. manufacturing output, and also that the extensive margin fluctuates notably over the business cycle. In addition, unconditional

duty-free imports of production machinery and materials (which became moot after NAFTA's phase-out of tariffs), and operation without ownership of assets. As production machinery and materials are received on loan from foreign parent firms or outsourcing clients, the maquiladora plants have no inventory or fixed assets, and thus are exempted from most asset taxes. The fiscal regime applicable to the maquiladora plants provides a strong incentive for the entire amount of the maquiladora's production to be exported (Sinclair, 1997; Hufbauer and Schott, 2005).

correlations at various lags and leads show that expansions in U.S. output precede the adjustment in the extensive margin by three-to-four quarters.

Next I investigate the *conditional* co-movement between U.S. manufacturing and offshore production in Mexico, as I estimate the conditional correlations and impulse responses of each of the two offshoring margins to U.S. permanent technology shocks. To this end, I identify U.S.-specific permanent technology shocks using long-run restrictions in a structural VAR model as in Gali (1999), which I adapt to an open-economy framework. My identification strategy relies on the following assumptions: (i) Long-run labor productivity in U.S. manufacturing responds exclusively to U.S.-specific permanent technology shocks; (ii) Conversely, long-run labor productivity in Mexico's maquiladora sector responds to both U.S. and Mexico-specific permanent technology shocks. The latter assumption relies on the fact that the maquiladora plants use exclusively loaned production machinery received from their foreign parent and client firms, most of which originate in the U.S.

The conditional correlation estimates indicate the following: (1) The intensive margin of offshoring (value added per existing maquiladora plant) adjusts instantaneously when a permanent technology shock boosts long-run labor productivity in U.S. manufacturing: The conditional correlation between the intensive margin and U.S. labor productivity is large and positive, in contrast to the unconditional correlation which is not statistically significant. (2) There is no immediate response along the extensive margin (the number of maquiladora plants) to U.S. technology shocks: The conditional correlation between the number of maquiladora plants and U.S. labor productivity is small and not statistically significant.

The estimated impulse responses for a U.S. permanent technology shock show that: (1)

The intensive margin of offshoring exhibits an immediate jump, which is followed by an additional hump-shaped increase. The intensive margin then declines below its initial level, and returns to it over time. (2) The extensive margin does not respond on impact, but rises above its initial level gradually over time, and stabilizes at a permanently higher level in the long run. (3) The impulse responses also suggest that a permanent U.S. technology shock has a disproportionate long-run effect on real output in U.S. manufacturing and in Mexico's maquiladora sector: The long-run effect on the maquiladora value added is 4.5 times greater than the corresponding effect on U.S. manufacturing.

I then use the estimated conditional correlations and impulse responses for U.S. technology shocks as empirical benchmarks to assess the implications of the model of offshoring with heterogeneous firms in Zlate (2008), in which the offshoring behavior of firms is driven by technology shocks in their country of origin. The qualitative implications of the model are consistent with the empirical impulse responses of the intensive and extensive margins of offshoring to Mexico. In the model, following a positive domestic technology shock, there is an immediate rise in offshoring along its intensive margin (value added per offshoring firm), which then declines below and returns to its initial level in the long run. The extensive margin (the number of offshoring firms) initially drops, but rises gradually and remains above its initial level in the long run.

The study of the dynamics of offshoring conducted by U.S. firms in Mexico is important because the relocation of production generates cross-country links in the form of trade flows (of intermediate goods shipped from the U.S. to Mexico, and processed goods from Mexico back to the U.S.) and foreign investment flows (when U.S. firms acquire subsidiaries

in Mexico).³ Thus, offshoring works as a transmission mechanism for business cycle fluctuations across the economies involved (Burstein, Kurz and Tesar, 2008), one that enhances the business cycle volatility in the host economy (Bergin, Feenstra and Hanson, 2008). Offshoring motivated by lower production costs is a particularly strong link between pairs of economies with different levels of economic development, such as the U.S. and Mexico, or the U.S. and economies in Central and South America.⁴

This paper is organized as follows. Section 2 describes Mexico's maquiladora sector and the data sources. Section 3 uses unconditional correlations to describe the co-movement between U.S. manufacturing and offshore production in Mexico. Section 4 presents the identification strategy, the structural VAR specification, and the estimated conditional correlations and impulse responses. Section 5 provides a comparison of the empirical conditional correlations and impulse responses with their theoretical counterparts generated by the model of offshoring in Zlate (2008). Section 6 summarizes the main conclusions of the paper.

2.2 Mexico's Maquiladora Sector

Mexico's maquiladora sector I study the dynamics of offshore production using quarterly aggregate data for U.S. manufacturing and Mexico's maquiladora sectors, for the

³The maquiladora sector accounts for 50 percent of Mexico's manufacturing exports; Mexico maquiladora's exports to the U.S. accounted for 5.3% of U.S. industry shipments over 2000-2003 (Bergin, Feenstra, Hanson, 2007, 2008).

⁴Data on the foreign operations of U.S. multinational firms shows that as much as 50 percent of the manufacturing sales of U.S. affiliates in Mexico and 26 percent of the sales of U.S. affiliates in Latin America as a whole were directed towards their U.S. parent firms in 2005, as opposed to only 3 and 5 percent of the sales of U.S. affiliates in Europe and Asia-Pacific (BEA, 2007). The pattern shows the large scope for offshoring motivated by lower production costs by U.S. firms in Latin America. A similar pattern exists between West European firms and the new member countries of the European Union (Marin, 2006; Meyer, 2006).

interval between 1990:1 and 2006:4. In particular, the Mexican data allows to compute the intensive and extensive margins of offshore production conducted by U.S. manufacturing firms in Mexico, which I measure as the real value added per maquiladora plant and the number of maquiladora plants, respectively.

Mexico's maquiladora sector is an appropriate example to study the offshoring operations of U.S. firms as a plausible transmission mechanism of business cycle fluctuations across countries, for several reasons. One is the strong link between U.S. manufacturing and Mexico's maquiladora sector, as the majority of the maquiladora plants accommodate the offshoring operations of U.S. firms. Motivated by lower production costs in Mexico, U.S. firms relocate segments of their production chain to the maquiladora sector through either vertical foreign direct investment or arm's length transactions. Although not all of the maquiladora plants have U.S. ownership,⁵ most of the maquiladora's imported inputs originate in the U.S. (82 percent in 2001, according to Hausman and Haytko, 2003), and most of the maquiladora's value added is exported to the U.S. (roughly 90 percent, as documented in Burstein, Kurz and Tesar, 2007).

Another reason is the large magnitude of the maquiladora sector relative to the Mexican economy. The maquiladora sector accounts for approximately 20 percent of Mexico's manufacturing value added (INEGI, 2009). It is responsible for 24.5 percent of Mexico's manufacturing employment (as of 2004) and for roughly half of Mexico's manufacturing exports (Bergin, Feenstra and Hanson, 2007, 2008).

In addition, one advantage of using the maquiladora data set is the availability of high-

⁵As of March 2002, 61 percent of the maquiladora plants had U.S. ownership, and only 27 percent had Mexican ownership (Solunet Infomex, 2009).

frequency time series data for a relatively long period of time (17 years at quarterly frequency). Nonetheless, the data set allows to separate the value added from the imported components incorporated in Mexico's maquiladora total output.

Data sources Data for Mexico's maquiladora sector (real value added, the number of plants, hours worked, employment, and remuneration of workers), at monthly frequency and aggregated at the sectoral level, is provided by Mexico's *Instituto Nacional de Estadística, Geografía e Informática* (INEGI, 2009). The maquiladora data originates from a monthly electronic survey of the approximately 3,000 establishments (plants) that were part of the Maquiladora Program, conducted by INEGI between 1990 and 2006.⁶ I aggregate the data into quarters and perform the seasonal adjustment using the X-12-ARIMA method of the U.S. Census Bureau.

Data for U.S. manufacturing is provided by the Board of Governors of the Federal Reserve System and by the U.S. Bureau of Labor Statistics, and is described into detail in Appendix 1.

2.3 Unconditional Correlations

In this section I use unconditional correlations of bandpass-filtered data to study the co-movement between U.S. manufacturing and Mexico's maquiladora activity, where I measure the latter as the total value added and the number of plants. I find that Mexico's

⁶The mandatory survey of Mexico's maquiladora establishments (which had the obligation to participate stipulated in the maquiladora operation rules) was interrupted in November 2006, when the Maquiladora Program was replaced by the "Manufacturing Industry, Mquiladora, and Export Services" (IMMEX) Program. The introduction of IMMEX, which merges the former Maquiladora Program with the "Temporary Imports for Exports" (PITEX) Program and regulates roughly 6,500 establishments, has generated continuity issues in the maquiladora time series data collected before and after 2006 (Durand Alcantara, 2007).

maquiladora total value added is pro-cyclical with fluctuations in U.S. manufacturing output, and also that maquiladora's intensive and extensive margins follow different dynamics over time. In particular, fluctuations in U.S. output tend to lead the extensive margin of offshore production in Mexico (the number of plants) by as much as four quarters.

U.S. manufacturing industrial production vs. Mexico maquiladora activity

In panels 1 and 3 of Figure 1 (left), I plot the two indicators of Mexico's maquiladora activity (real value added and number of plants) against the industrial production index for U.S. manufacturing. I apply the Baxter-King bandpass-filter to the quarterly data in natural logs for the interval 1990:1-2006:4 in order to eliminate fluctuations with periodicity lower than 18 months and greater than eight years.⁷

The visual inspection of the filtered data suggests that the U.S. economic expansion throughout the 1990s, as well as the recession in 2001, were associated with similar developments in the maquiladora sector. The unconditional correlations of U.S. output with the maquiladora value added and number of plants, summarized in panels 2 and 4 of Figure 1, shows that offshoring to Mexico is pro-cyclical with the fluctuations in U.S. manufacturing.

The unconditional correlations also suggest that a stronger contemporaneous co-movement exists between U.S. manufacturing output and the total maquiladora value added than between U.S. output and the number of maquiladora plants: For the former, the contemporaneous correlation is positive (0.71) and reaches a peak for U.S. output lagged by only two quarters (0.85). For the latter, the contemporaneous correlation is relatively lower (0.50) and increases considerably for U.S. output lagged by four quarters (0.82).⁸ The results

⁷For a description of the bandpass filter, see Stock and Watson (1999).

⁸A non-trivial fraction of the maquiladora plants have Mexican ownership (27 percent in March 2002,

show that the intensive and extensive margins of offshoring follow different dynamics over time. The fact that U.S. output fluctuations lead the number of maquiladora plants by more than they lead the total maquiladora value added suggests that: (i) the extensive margin adjustment is relatively slower than the total, and (ii) the contemporaneous adjustment in the total value added takes place mostly through the intensive margin (value added per plant). I explore this hypothesis in the next section, where I use conditional correlations for country-specific technology shocks to describe the co-movement between U.S. manufacturing and the two margins of Mexico's maquiladora value added.

U.S.-Mexico relative wage vs. Mexico maquiladora activity The unconditional correlations in Figure 2 also describe an interesting link between offshoring and fluctuations in the relative wage. In panels 1 and 3 (left) I plot the two maquiladora indicators (total value added and the number of plants) along with the ratio of nominal hourly wages in U.S. manufacturing and Mexico's maquiladora sector, expressed in the same currency. The corresponding correlations are summarized in panels 2 and 4 (right).

The correlations between each maquiladora indicator and the *past* U.S.-Mexico wage ratios are positive: Past increases in the U.S. manufacturing hourly wage relative to Mexico maquiladora's wage are followed by the relocation of production from the U.S. to Mexico. Also, the correlations between each maquiladora indicator and the *future* wage ratios are negative: The relocation of production to Mexico is associated with a future decline in the relative wage ratio, which can be caused by either a U.S. wage moderation or an increase

according to Solunet Infomex, 2009). These plants represent arm's length contractors that have the flexibility to enter and exit from outsourcing relationships with U.S. firms over the business cycle. Other maquiladora plants function on a seasonal basis. Both of these facts explain the relatively short adjustment time (four quarters after expansions in U.S. manufacturing) for the number of maquiladora plants in Mexico.

in Mexico's maquiladora wage.⁹ This empirical result is consistent with the model of endogenous offshoring with heterogeneous firms and fixed relocation costs in Zlate (2008), in which the adjustment in the extensive margin of offshoring (the number of offshore plants) is driven by fluctuations in the relative cost of effective labor.

2.4 Conditional Correlations for U.S. Technology Shocks

This section presents the main contribution of the paper: I examine the co-movement between output in U.S. manufacturing and the intensive and extensive margins of Mexico's maquiladora sector, *conditional* on identified U.S. permanent technology shocks. This approach contrasts to the one in the previous section, in which I use *unconditional* correlations of the bandpass-filtered data to study the corresponding co-movements.

2.4.1 Identification strategy

I estimate a structural vector autoregressive (VAR) model in a two-country framework, using long-run restrictions in order to identify country-specific permanent technology shocks. My identification strategy relies on the assumption that long-run labor productivity in U.S. manufacturing responds exclusively to U.S. permanent technology shocks. It does not respond to technology and non-technology shocks originating in Mexico. Conversely, long-run labor productivity in Mexico's maquiladora sector responds to both U.S. and Mexico-specific permanent technology shocks.

The identification assumption is justified by the fact that Mexico's maquiladora program

⁹The former effect is due to reasons such as higher demand for Mexican labor or higher training expenses in the maquiladora sector.

involves operations without ownership of assets: The maquiladora plants in Mexico (with or without foreign ownership) use production machinery and materials received on loan from their parent or client companies abroad (Sinclair, 1997), most of which originate in the U.S.¹⁰ In turn, the use of borrowed U.S. production machinery affects labor productivity in Mexico's maquiladora plants, and justifies the assumption that U.S. permanent technology shocks affect the long-run level of labor productivity in Mexico's maquiladora sector. The reverse does not happen: Mexican technology shocks do not affect U.S. labor productivity in the long run.

My work builds on the closed-economy structural VAR framework of Gali (1999), in which the identification strategy uses the restriction that long-run labor productivity responds exclusively to a permanent technology shock. I expand the framework to an open-economy context, and introduce an alternative identification strategy for country-specific shocks to the one used by Corsetti, Dedola, and Leduc (2006) (CDL). In the open-economy framework of CDL, the variable assumed to respond exclusively to the country-specific permanent technology shock is the (log of) long-run labor productivity in the U.S. measured *in deviation* from the (log of) long-run labor productivity in the "rest of the world." In contrast to CDL, I include the levels of labor productivity for both U.S. manufacturing and Mexico's maquiladora sector as two separate variables in my structural VAR specification.

¹⁰As of March 2002, 61 percent of the 2,762 maquiladora plants surveyed had U.S. ownership, and only 27 percent had Mexican ownership (Solunet Infomex, 2009). MacLachlan and Aguilar (1998) also show that, as of 1996, less than half (45 percent) of Mexico's maquiladora plants had Mexican ownership.

2.4.2 Empirical specification

In order to examine the responses of the intensive and extensive margins of offshore production to U.S. technology shocks, I estimate the following structural VAR model with five variables. I use quarterly data for U.S. manufacturing and offshore production to Mexico's maquiladora sector over the period 1990:1-2006:4.

$$\begin{bmatrix} \Delta x_t^{US} \\ \Delta x_t^{Mex} \\ Z_t \end{bmatrix} = \begin{bmatrix} D^{11}(L) & D^{12}(L) & D^{13}(L) \\ D^{21}(L) & D^{22}(L) & D^{23}(L) \\ D^{31}(L) & D^{32}(L) & D^{33}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{bmatrix}. \quad (2.1)$$

In the above specification, x_t^{US} denotes (the log of) labor productivity in U.S. manufacturing, which is the variable that responds in the long run exclusively to the U.S. permanent technology shock ($\varepsilon_{1,t}$). Variable x_t^{Mex} denotes (the log of) labor productivity in Mexico's maquiladora sector that responds in the long run to both U.S. and Mexico-specific technology shocks ($\varepsilon_{1,t}$ and $\varepsilon_{2,t}$), but not to the structural non-technology shocks ($\varepsilon_{3,t}$). In addition, the 3×1 vector $Z_t = [int_t, \Delta ext_t, \Delta h_t^{US}]'$ includes variables int_t and ext_t , which denote the intensive and extensive margins of offshore production in Mexico (measured as value added per plant, and the number of plants in the maquiladora sector, respectively, both expressed in logs), as well as variable h_t^{US} , which denotes the log of hours worked in U.S. manufacturing.¹¹ The structural shocks are not correlated and have unit variance ($E\varepsilon_t\varepsilon_t' = I$), where $\varepsilon_{1,t}$ denotes the technology shock that is specific to U.S. manufacturing, $\varepsilon_{2,t}$ is the technology shock specific to Mexico's maquiladora sector, and $\varepsilon_{3,t}$ is a 3×1 vector

¹¹I normalize and take natural logs of each variable. For instance, $x^{US}(t) = 100 + 100 * \ln[x^{US}(t)/x^{US}(1990:1)]$.

of structural non-technology shocks.

In addition to the five variables mentioned above, the specification in 2.1 allows to recover the responses of U.S. manufacturing output (computed as $ip_t^{US} = x_t^{US} + h_t^{US}$), the total value added in Mexico ($va_t = int_t + ext_t$), and the number of hours worked in Mexico's maquiladora sector ($h_t^{Mex} = va_t - x_t^{Mex}$) to the structural shocks.

The identification strategy with long-run restrictions uses the property that $D(1) = \sum_{j=0}^{\infty} D_j$ is the matrix of long-run responses to the vector of orthogonal shocks, where D_j are the coefficients of the lag polynomial $D(L) = D_0 + D_1L + D_2L^2 + \dots$. Thus, imposing that $D^{12}(1) = 0$ and $D^{13}(1) = 0$ reflects the identifying restriction that the unit root in U.S. manufacturing labor productivity originates exclusively in the U.S. manufacturing technology shock. In addition, identification of the system of equations implied by 2.1 also requires that the elements of 1×3 vector $D^{23}(1)$ are zero and that the 3×3 matrix $D^{33}(1)$ is lower triangular (see Appendix 2).

The specification in 2.1 assumes that, with the exception of the intensive margin of offshoring (value added per plant), all other variables (labor productivity in the U.S. and in Mexico, the number of maquiladora plants, and the number of hours worked in U.S. manufacturing) have a unit root. Indeed, the standard Dickey-Fuller test for unit root performed on the data *in levels* fails to reject the null hypothesis of unit root for all variables with the exception of the intensive margin (See Table 3 in Appendix 3). The results for the data *in differences* reject the unit root hypothesis for all variables. Therefore, I take first differences for all variables with the exception of the intensive margin of offshore production, for which I use deviations from a linear time trend. Finally, the results of the Engle-Granger test do not reject the null hypothesis of no cointegration between labor productivity in U.S.

manufacturing and labor productivity in Mexico’s maquiladora sector (see Appendix 3).

2.4.3 Results

In this section I report the estimates of conditional correlations and impulse responses to permanent technology shocks in U.S. manufacturing. Following Gali (1999), I use the estimate of the lag polynomial $D(L)$, which embeds the impulse response coefficients for the five variables in specification 2.1 with respect to the structural shocks, to compute the conditional correlations as:

$$\rho(\Delta x_t^{US}, \Delta ext_t | i) = \frac{\sum_{j=0}^{\infty} D_j^{\Delta x^{US}, i} D_j^{\Delta ext, i}}{\sqrt{\text{var}(\Delta x_t^{US} | i) \text{var}(\Delta ext_t | i)}}, \quad (2.2)$$

where i denotes that the correlation estimate is conditional on one of the five structural shocks (i.e. U.S.-specific technology, Mexico-specific technology, or three other non-technology shocks); $\text{var}(\Delta x_t^{US} | i) = \sum_{j=0}^{\infty} (D_j^{\Delta x^{US}, i})^2$ and $\text{var}(\Delta ext_t | i) = \sum_{j=0}^{\infty} (D_j^{\Delta ext, i})^2$ are the variances of U.S. labor productivity and the number of maquiladora plants (measured in growth rates), respectively, each conditional on the shock type i .

Unconditional and conditional correlations

Table 1 reports the unconditional and conditional correlations¹² between variables describing U.S. manufacturing and those describing offshore production in Mexico’s maquiladora sector: (a) the intensive margin (value added per maquiladora plant); (b) the extensive

¹²The (*) and (**) superscripts denote statistical significance at the 10 and 5 percent levels. Standard errors for conditional correlations have been computed as in Gali (1999), using a Monte Carlo approach to sample from the asymptotic distribution of coefficients and the variance-covariance matrix of reduced-form innovations.

margin (number of plants); and (c) the total value added. All conditional correlations are computed for U.S. permanent technology shocks. (The only exception is the correlation between Mexico's labor productivity and hours worked on the third row of Panel C, which is conditional on Mexican technology shocks.) The correlations are computed for all variables measured in growth rates.

Table 1. Unconditional and conditional correlations (with standard errors)

	Unconditional	Conditional on U.S. technology shocks
Panel A		
(a) U.S. productivity vs. Mexico intensive mg.	0.25 (0.16)	0.64** (0.27)
(b) U.S. productivity vs. Mexico extensive mg.	-0.17 (0.22)	-0.06 (0.38)
(c) U.S. productivity vs. Mexico value added	0.10 (0.13)	0.50 (0.32)
Panel B		
(a) U.S. output vs. Mexico intensive margin	0.29* (0.15)	0.49* (0.30)
(b) U.S. output vs. Mexico extensive margin	0.19 (0.16)	0.33 (0.39)
(c) U.S. output vs. Mexico total value added	0.54** (0.17)	0.82** (0.34)
Panel C		
(a) U.S. productivity vs. U.S. hours	-0.16 (0.17)	-0.67** (0.34)
(b) Mexico productivity vs. Mexico hours	-0.71* (0.37)	-0.74** (0.32)
(c) U.S. productivity vs. Mexico hours	0.12 (0.15)	0.44 (0.36)

U.S. manufacturing labor productivity vs. offshore production in Mexico

The key results are presented in Panel A of Table 1, which reports the correlations between U.S. labor productivity and each of the three indicators of offshore production. The results suggest that the intensive margin of offshoring adjusts instantaneously when a permanent technology shock boosts long-run labor productivity in U.S. manufacturing. While the unconditional correlations are not statistically significant, the conditional correlation between the U.S. technology-driven components of U.S. labor productivity and the intensive margin of offshoring is positive (0.64) and statistically significant at the 5 percent level. However, there is no immediate response of the extensive margin to the U.S. technology shock. The conditional correlation between U.S. productivity and the extensive margin of offshoring is small and not statistically significant. Overall, the conditional correlation between U.S. productivity and the total value added offshore is positive, and lies at the borderline of statistical significance.

Figure 2 provides graphical counterparts to the correlations reported in Table 1 (Panel A). For each pair of variables, the unconditional correlations correspond to the line charts and scatterplots of the *original data* in Figure 2. The conditional correlations correspond to the line charts and scatterplots of the *U.S. technology-driven components* of U.S. labor productivity and offshore production recovered from the identified VAR.

The close co-movement between the U.S. technology-driven components of U.S. labor productivity and the maquiladora's intensive margin is particularly visible in the corresponding scatterplot in Figure 2(b), in which the observation points are concentrated along the upward-sloping diagonal. In contrast, the scatterplot of the original data in Figure 2(b) shows no obvious pattern of the observation points.

U.S. manufacturing output vs. offshore production in Mexico Panel B in Table 1 reports the unconditional and conditional correlations between U.S. manufacturing output and the same three indicators of offshore production in Mexico. The results reinforce the findings already presented in Panel A above: The value added per plant in Mexico rises instantaneously when a positive technology shock causes an expansion in U.S. manufacturing. The conditional correlation between the U.S. technology-driven components of U.S. output and the intensive margin of offshoring is positive (0.49) and statistically significant. The unconditional correlation is also positive, but conditioning on the U.S. technology shock enhances the correlation.

Both the unconditional and conditional correlations between U.S. manufacturing output and Mexico's maquiladora total value added are positive and statistically significant, but conditioning on the U.S. technology shock enhances the correlation. The result shows that, when a positive technology shock leads to an expansion in U.S. manufacturing output, the instantaneous rise in the total value added offshore in Mexico is due to the intensive margin adjustment.

Labor productivity vs. hours The specification in 2.1 also allows for an empirical study of the responses of hours and labor productivity to country-specific technology shocks, along the lines of Gali (1999). The results in Panel C of Table 1 show that the conditional correlation between the U.S. technology-driven components of hours worked and labor productivity growth in U.S. manufacturing is negative and statistically significant, a result which is in line with the findings in Gali (1999). In Mexico, the conditional correlation between hours worked and labor productivity for Mexican technology shocks is also negative

and statistically significant. In line with the conditional correlations, the scatterplots in Figure 4(b) illustrate the strong negative relationship between the technology-driven components of labor productivity and hours (measured as growth rates) for either the U.S. or Mexico. Nonetheless, the conditional correlation between U.S. labor productivity and Mexico maquiladora's hours for U.S. technology shocks is positive, although not statistically significant.

Impulse responses

Figure 5 shows the estimated impulse responses for the three indicators of offshore production (the intensive margin, the extensive margin, and total value added, each measured in levels) to U.S. permanent technology shocks. The figure also reports the ± 2 standard error confidence intervals.

Following a one-standard deviation positive U.S. technology shock, labor productivity in U.S. manufacturing increases immediately by almost 0.5 percent and stabilizes at a permanently higher level. The intensive margin of offshoring (value added per maquiladora plant) exhibits an immediate jump of almost 0.6 percent, followed by an additional increase until it reaches a peak at 1.3 percent of its initial level two quarters after the shock. The intensive margin then declines below its initial level (nine quarters after the shock), and returns to it over time. In contrast, the extensive margin (the number of maquiladora plants) does not react on impact, but rises above its initial level 4 quarters after the shock, and stabilizes at a permanently higher level in the long run.

The response of maquiladora's total value added combines the separate adjustments of the intensive and extensive margins described above. The total value added jumps on

impact (although the effect is not statistically significant) and continues to rise afterwards, eventually stabilizing at a permanently higher level (4.5 percent above the initial level, statistically significant) 20 quarters after the shock. Thus, a permanent U.S. technology shock has a disproportionate long-run effect of on U.S. manufacturing output and on Mexico's maquiladora value added: the former rises by a mere 1 percent in the long run, as compared to 4.5 percent for the latter.

The impulse responses of the intensive and extensive margins of offshoring for a U.S. technology shock explain the differences between their conditional correlations with U.S. labor productivity. On one hand, the immediate jump in the intensive margin causes the large and positive correlation between U.S. labor productivity and the intensive margin conditional on U.S. technology shocks. On the other hand, the lack of an immediate response of the extensive margin explains the small conditional correlation (and not statistically significant) between U.S. labor productivity and the number of maquiladora plants.

2.5 Data vs. Model: Impulse Responses and Conditional Correlations

In this section I compare the intensive and extensive margin dynamics of the offshore production undertaken by U.S. firms in Mexico (illustrated by the conditional correlations and impulse responses above) to their theoretical counterparts generated by the model of offshoring in Zlate (2008), in the presence of country-specific technology shocks.

2.5.1 Model summary

I study the intensive and extensive margin dynamics of offshoring in a two-country (North and South), dynamic stochastic general equilibrium model with endogenous firm entry and heterogeneous firms (Zlate, 2008). In the model, firm entry in the country of origin (North) is subject to a sunk cost reflecting the regulation of starting a business. Every period, an unbounded pool of potential entrant firms in the North face a trade-off between the sunk entry cost (expressed in units of Northern effective labor) and the expected stream of future profits, as in Ghironi and Melitz (2005). Following entry in the country of origin (North), each firm is assigned an idiosyncratic labor productivity factor drawn independently from a common distribution over a support interval, and produces a different variety of final goods under monopolistic competition.¹³

Every period after domestic entry, each firm in the North chooses between either domestic or foreign inputs (labor) to use in the production of final goods. The use of Southern inputs ("offshoring") provides the advantage of a lower cost of effective labor,¹⁴ but involves a per-period, fixed offshoring cost (expressed in units of Southern labor) needed to establish and maintain the offshore production plant. (I assume a one-to-one identification relationship between a firm and a plant throughout the model.¹⁵) In addition, offshoring

¹³Following entry, firms keep the idiosyncratic productivity factor for the entire duration of their lives. Independently of the idiosyncratic productivity, each firm faces the possibility of exogenous exit with probability δ every period.

¹⁴I define the cost of effective labor as the ratio between the real wage and aggregate productivity (w_t/Z_t in the North and w_t^*/Z_t^* in the South). I derive an asymmetric steady state, in which the difference in the regulation of firm entry in each economy generates the difference in real effective wages across countries. In the model, I set firm entry costs to be higher in the South; since less firms enter the more regulated economy, labor demand and the cost of effective labor are lower in the South.

¹⁵I maintain the assumption of one-to-one identification between a firm, a plant, and a final good variety, as in Bilbiie, Ghironi and Melitz (2006). Under this assumption, the extensive margin of offshoring can be interpreted as the number of firms or plants every period; the intensive margin is the value added per offshoring firm or plant.

involves the so-called iceberg trade cost that reflects transportation costs and trade barriers affecting the shipping of final good varieties produced offshore (in the South) back to the country of origin (North).

When deciding on where to locate production (domestically vs. offshore), each firm balances the lower foreign costs of effective labor against the fixed and trade costs associated with offshore production. Since firms are heterogeneous in productivity, the decision to produce offshore is firm-specific: Ranking firms after their idiosyncratic productivity factor over the support interval, the marginal firm that lies at the productivity cutoff (a state variable) is indifferent between producing domestically or offshore. Only the more productive firms (with idiosyncratic productivity above the cutoff) can afford the fixed cost of offshoring.

Following a positive technology shock in the North, increased domestic firm entry and the resulting appreciation of the Northern effective wage cause a gradual increase in the number of offshoring firms (the extensive margin). On impact, however, the increased consumption demand for all final good varieties - including those already being produced offshore - causes an instantaneous increase in the value added per offshoring firm (the intensive margin).

2.5.2 Impulse responses

Using the benchmark specification with financial autarky and inelastic labor supply, I log-linearize the model around the steady state and compute the impulse responses to a one percent-increase in aggregate productivity in the North. I assume that labor productivity

in the North is described by the univariate process:

$$\log Z_{t+1} = \rho \log Z_t + u_t, \tag{2.3}$$

in which the persistence parameter ρ takes the values 0.99, 0.95 and 0.90, and u_t is the technology shock affecting labor productivity. Figure 7 shows the impulse responses of the model to a one standard deviation technology shock with various degrees of persistence. For each variable, the horizontal axis shows the number of quarters after the initial shock, and the vertical axis shows the percentage deviations from the original steady state in each quarter.

The intensive margin of offshoring On impact, the one percent-increase in aggregate labor productivity in the North causes a jump in the intensive margin of offshoring (value added per offshoring firm), a result which is in line with the impulse responses obtained from the structural VAR. The spike in the intensive margin is generated by the increased demand for the consumption basket, which is a C.E.S. composite of the final good varieties produced both domestically and offshore. The magnitude of the initial spike varies with the persistence of the technology shock: A more persistent technology shock leads to a larger increase in the expected stream of future income for the representative household in the North, and thus to a larger increase in consumption demand.

Following the initial jump, the value added per offshore plant declines. The decline reflects the substitution in consumption away from varieties produced offshore (which initially become relatively more expensive due to the scarcity of units of effective labor in the South) and towards the cheaper varieties produced domestically (which initially are rela-

tively cheaper due to the increased productivity of Northern labor). The decline continues until the intensive margin drops below its initial level, after which it recovers and returns to its initial level in the long run, a result which is consistent with the empirical impulse response discussed above.

The extensive margin of offshoring On impact, the increased demand for all varieties of final goods - including for varieties produced offshore - causes an immediate increase in the real wage in the South: Since the increase in aggregate labor productivity in the North is not replicated in the South, on impact there is excess demand for units of Southern effective labor. As a result, the number of Northern firms that produce offshore (the extensive margin) declines on impact - a counter-factual result - due to: (1) the increase in the effective cost of producing offshore, and (2) the increase in the fixed cost of relocation, both of which are sensitive to the cost of effective labor in the South.

Over the business cycle, as aggregate labor productivity in the North persists above the initial steady state, the larger market size encourages firm entry (a flow variable), which causes the total number of firms in the North (a stock variable) to increase gradually over time. In turn, the gradual increase in the demand for Northern labor causes the real wage to increase faster than aggregate productivity, and thus the cost of effective labor in the North to appreciate relative to that in the South (i.e. the "terms of labor" appreciate).¹⁶ Due to the gradual appreciation of the terms of labor, more of the Northern firms will relocate production to the South over time. (The productivity cutoff moves downward along the support interval, so that more of the less productive firms relocate production

¹⁶The absence of firm entry would cause the wage to increase just as fast as productivity, which would leave the cost of effective labor and the number of offshoring firms unchanged.

offshore over time). Thus, the extensive margin of offshoring rises gradually over time (rather than instantaneously on impact), a result which is consistent with the empirical evidence discussed in the previous section.

2.5.3 Conditional correlations

In Table 2, I contrast the conditional correlations¹⁷ from the data to their model-generated counterparts for country-specific technology shocks.

Table 2. Conditional correlations for U.S. technology shocks, data vs. model

Conditional correlations:	Data	Model		
		$\rho = 0.90$	$\rho = 0.95$	$\rho = 0.99$
U.S. output vs. Mex. intensive margin	0.49* (0.30)	0.71	0.85	0.97
U.S. output vs. Mex. extensive margin	0.33 (0.39)	-0.61	-0.78	-0.96
U.S. output vs. Mex. total value added	0.82** (0.34)	-0.31	-0.48	-0.84

First, the model generates a positive and large conditional correlation between output in the North and the intensive margin of offshoring - conditional on a positive technology shock in the North - a result which is line with the data. The positive conditional correlation in the model is due to the initial spike in the intensive margin, caused by the increased demand for final good varieties produced offshore. The correlation increases when a more persistent technology shock causes a larger initial jump in consumption demand.

¹⁷The (*) and (**) superscripts denote statistical significance at the 10 and 5 percent levels. Standard errors for conditional correlations have been computed as in Gali (1999), using a Monte Carlo approach to sample from the asymptotic distribution of coefficients and the variance-covariance matrix of reduced-form innovations.

Second, the model generates a negative conditional correlation between output in the North and the extensive margin, which reflects the initial decline in the number of offshoring firms caused by the sudden appreciation of the Southern effective wage. In the data, the corresponding correlation is positive but not statistically significant.

Third, the model generates a negative correlation between output in the North and the total value added of offshoring. This counter-factual result is generated by the large initial decline in the number of offshoring firms, which more than offsets the initial increase in the value added per firm. However, following its initial decline, the total value added recovers quickly and increases above its initial level in the long run, a theoretical result which is consistent with the empirical impulse response for maquiladora's total value added.

2.6 Conclusion

The conditional correlation and impulse responses for country-specific technology shocks provide additional insight on the dynamics of offshore production undertaken by U.S. firms in Mexico's maquiladora sector. For instance, the conditional correlation between labor productivity in U.S. manufacturing and the value added per offshore plant in Mexico (the intensive margin) - conditional on a U.S. permanent technology shock - is positive and statistically significant, whereas the unconditional correlation is inconclusive. The result shows that, when a permanent technology shock boosts long-run labor productivity in U.S. manufacturing, an instantaneous adjustment takes place along the intensive margin of offshore production in Mexico.

The estimated impulse responses also show that the time pattern of maquiladora's ad-

justment in response to U.S. technology shocks differs across the intensive margin (value added per plant) and extensive margins (number of plants). Following a permanent U.S. technology shock, the intensive margin exhibits an immediate jump, then declines below its initial level, and finally returns to it over time. In contrast, the extensive margin does not react on impact, but rises above its initial level and stabilizes at a permanently higher level in the long run.

The conditional correlations and impulse response estimates for country-specific technology shocks also constitute useful empirical benchmarks to assess the implications of the two-country model of offshoring in Zlate (2008). The qualitative implications of the model are consistent with the empirical evidence on the intensive and extensive margins of offshoring to Mexico described above. In the presence of a positive technology shock affecting labor productivity in the country of origin, the model generates an immediate increase in the intensive margin of offshore production. The extensive margin declines on impact, but recovers quickly afterwards and increases above its initial level in the long run.

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2.A Appendix

2.A.1 Data summary

I use quarterly data for U.S. manufacturing and Mexico's maquiladora sector over the period 1990:1-2006:4.

- For U.S. manufacturing real output, I use the Industrial Production index for Manufacturing (NAICS), at quarterly frequency and seasonally adjusted, provided by the Board of Governors of the Federal Reserve System,
<http://www.federalreserve.gov/datadownload/default.htm>
- I construct the number of employee-hours in U.S. manufacturing from "Average Weekly Hours: Manufacturing" and "Employees on Nonfarm Payrolls: Manufacturing," provided by the Bureau of Labor Statistics through the Federal Reserve Employment Database, <http://research.stlouisfed.org/fred2/> I aggregate the seasonally-adjusted monthly data into quarters.
- Data for Mexico's maquiladora sector (real value added, employee-hours, employment, the number of establishments), at monthly frequency and without seasonal adjustment, is provided by the *Instituto Nacional de Estadística, Geografía e Informática* (INEGI), <http://dgcnesyp.inegi.org.mx/cgi-win/bdieintsi.exe>. I aggregate the data at quarterly frequency, and perform the seasonal adjustment using the X-12-ARIMA method of the U.S. Census Bureau.
- I construct the relative wage in U.S. manufacturing and Mexico maquiladora from the nominal hourly wage in U.S. manufacturing ("Average Hourly Earnings: Manufacturing," provided by the Bureau of Labor Statistics through the Federal Reserve Employment Database) and Mexico's maquiladora sector (from "Remuneraciones > Nominales por persona ocupada" and "Horas promedio por persona," provided by INEGI), expressed in the same currency using the nominal exchange rate.

2.A.2 Structural VAR model and notation

Let Y_t be the 5×1 vector $[\Delta x_t^{US}, \Delta x_t^{Mex}, int_t, \Delta ext_t, \Delta h_t^{US}]'$. I define the *reduced-form VAR* model as:

$$A(L)Y_t = u_t, \quad (2.4)$$

where $A(L) = I - A_1L - A_2L^2 - \dots - A_pL^p$ is a finite-order polynomial in the lag operator, u_t is the 5×1 vector of reduced-form innovations, and $E u_t u_t' = \Sigma_u$ is their variance-covariance matrix.

The *structural VAR* model is:

$$B(L)Y_t = \varepsilon_t, \quad (2.5)$$

where the structural shocks ε_t are not correlated and have unit variance ($E \varepsilon_t \varepsilon_t' = I$).

I assume that a matrix R exists (square and invertible), so that the vector of reduced-form innovations u_t spans the space of structural shocks ε_t :

$$\varepsilon_t = R u_t. \quad (2.6)$$

The moving average representation of the structural VAR model is:

$$Y_t = A(L)^{-1} u_t = A(L)^{-1} R^{-1} \varepsilon_t = D(L) \varepsilon_t, \quad (2.7)$$

where $D(L) = A(L)^{-1} R^{-1} = D_0 + D_1 L + D_2 L^2 + \dots$ embeds the impulse response coefficients of Y_t with respect to the structural shocks ε_t . The identification strategy based on long run restrictions uses the property that $D(1) = \sum_{j=0}^{\infty} D_j$ is the long-run effect of the structural shocks ε_t on Y_t .

Next I introduce Ω , the long-run variance-covariance matrix of Y_t , as:

$$\Omega = A(1)^{-1} \Sigma_u A(1)^{-1'} = A(1)^{-1} \underbrace{R^{-1} \varepsilon_t \varepsilon_t' R^{-1'}}_{\Sigma_u} A(1)^{-1'} \quad (2.8)$$

$$= D(1) D(1)'. \quad (2.9)$$

The structural VAR model is identified if the system of 10 equations (resulting from expres-

sion 2.8 above) can be solved for just as many unknowns in matrix R , which can be achieved by restricting the 5×5 matrix to be lower-triangular. The restriction on R implies that $D(1)$ is also lower-triangular, and thus $D(1)$ can be obtained as the Cholesky factorization of Ω . Finally, $R = [D(1)A(1)]^{-1}$.

The identification restriction that the long-run labor productivity in U.S. manufacturing responds exclusively to U.S.-specific permanent technology shocks requires that matrix R be lower-triangular. Once the long-run variance-covariance matrix of Y_t is estimated as $\hat{\Omega} = \hat{A}(1)^{-1}\hat{\Sigma}_u\hat{A}(1)^{-1'}$ based on the estimated parameters of the reduced-form VAR, the estimate of R is obtained as:

$$\hat{R} = \left[Chol(\hat{\Omega})\hat{A}(1)\right]^{-1}. \quad (2.10)$$

2.A.3 Unit root tests for the data in levels and differences

Dickey-Fuller test for unit root The table below summarizes the results of the Dickey-Fuller unit root test with intercept, trend and one lag performed for the data in both levels and differences. There were 66 observations for the data in levels (regression run from 1990:03 to 2006:04) and 65 observations for the data in differences (regression run from 1990:04 to 2006:04).

Table 3. Dickey-Fuller tests for unit root

(A) T-test statistics for the data in levels								
x_t^{US}	x_t^{Mex}	$(x_t^{US} - x_t^{Mex})$	int_t	ext_t	va_t	h_t^{US}	h_t^{Mex}	gdp_t^{US}
-2.45	-1.81	-1.84	-5.21	-1.40	-1.05	-1.42	-0.89	-1.44
(B) T-test statistics for the data in differences								
Δx_t^{US}	Δx_t^{Mex}	$\Delta(x_t^{US} - x_t^{Mex})$	Δint_t	Δext_t	Δva_t	Δh_t^{US}	Δh_t^{Mex}	Δgdp_t^{US}
-3.62	-4.11	-4.12	-6.55	-4.03	-5.30	-3.29	-3.44	-3.83
Critical values: 1% = -4.10 5% = -3.48 10% = -3.17								

For the data *in levels*, the test statistics exceed the critical values for the 10 percent significance level for all variables - for which I cannot reject the null hypothesis of a unit

root - with the exception of the intensive margin. For the data *in differences*, the test statistics do not exceed the critical values for the 10 percent significance levels for any variable. (They do not exceed the critical values for the 5 percent significance levels for most of the variables). Thus, I reject the null hypothesis of a unit root for the data in differences.

Engle-Granger test for cointegration I test for the possibility of cointegration between labor productivity in U.S. manufacturing and in Mexico's maquiladora sector (i.e. which are two non-stationary variables). The Engle-Granger procedure requires performing an augmented Dickey-Fuller test on the residual obtained from the OLS regression of one variable on the other. Under the null hypothesis, the residual is non-stationary. Testing with one additional lag, there were 66 observations for the residuals obtained from the regression run from 1990:03 to 2006:04. The test statistic (-2.46) exceeds the critical value for the 10 percent significance level (-3.60). (The other critical values are -3.92 and -4.57 for the 5 and 1 percent significance levels, respectively.) Thus, I cannot reject the null hypothesis of non-stationary residuals, and conclude that the two variables are not cointegrated.

Figure 1. U.S. manufacturing industrial production (IP) vs. offshore production in Mexico (bandpass-filtered data in log-levels)

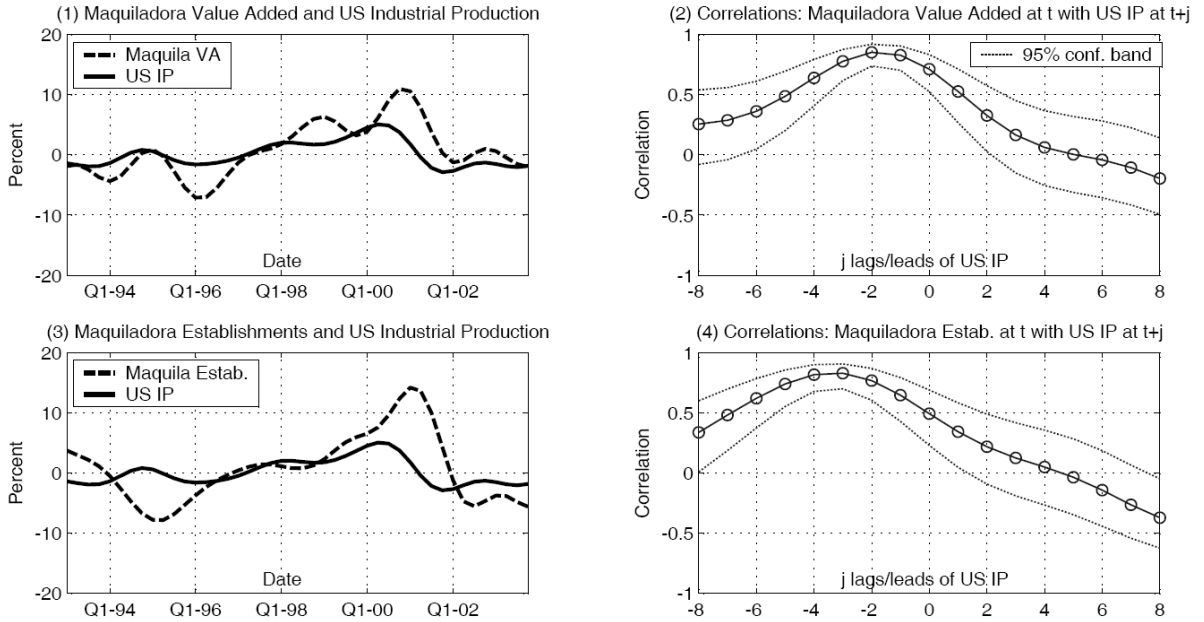


Figure 2. U.S.-Mexico relative manufacturing wage vs. offshore production in Mexico (bandpass-filtered data in log-levels)

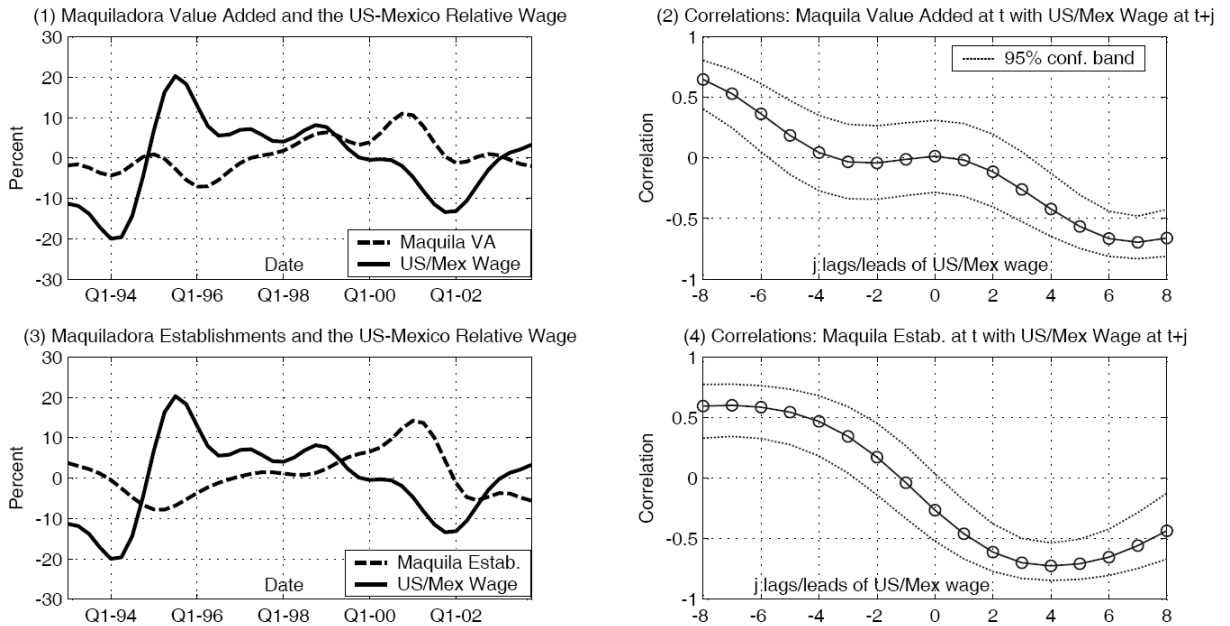
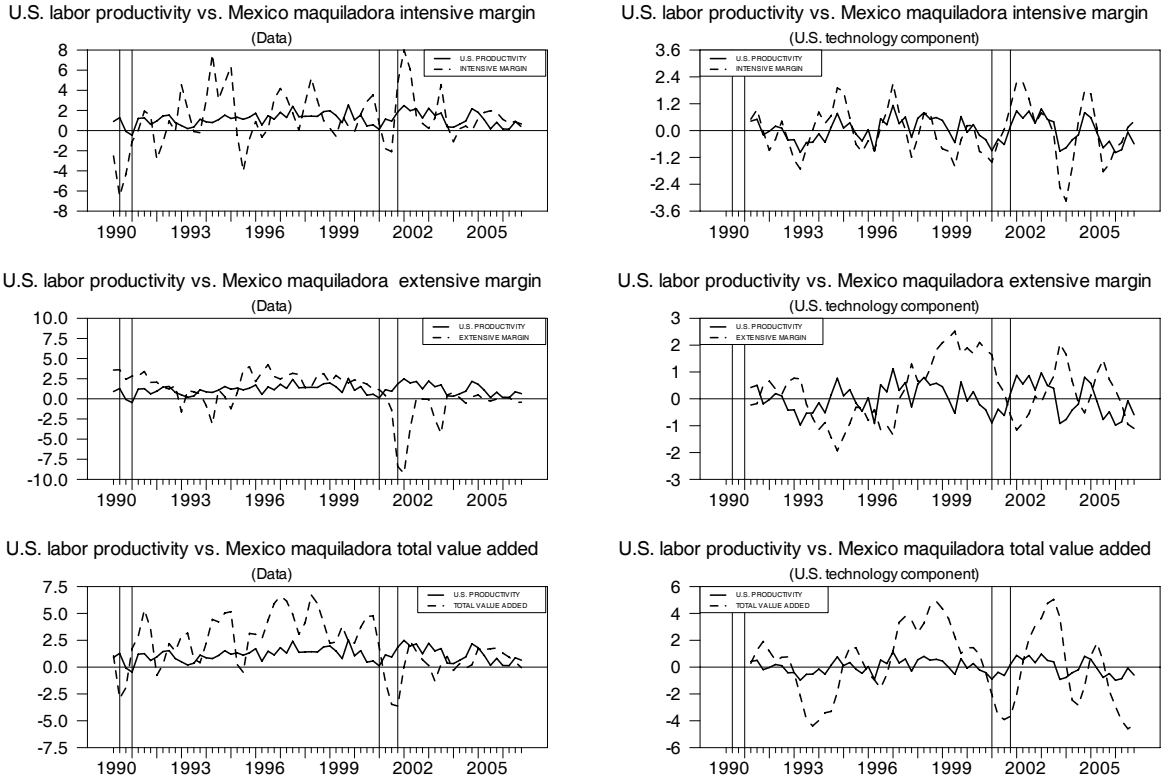


Figure 2. U.S. manuf. labor productivity vs. offshore production in Mexico (growth rates)

(a) Line charts



(b) Scatterplots

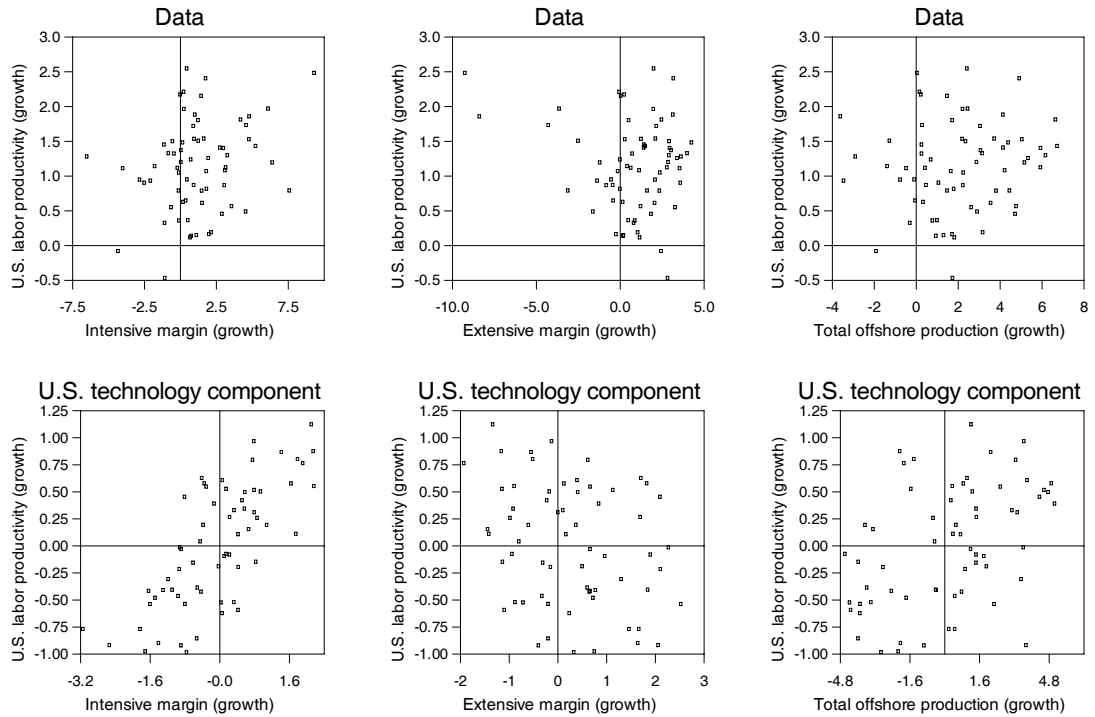
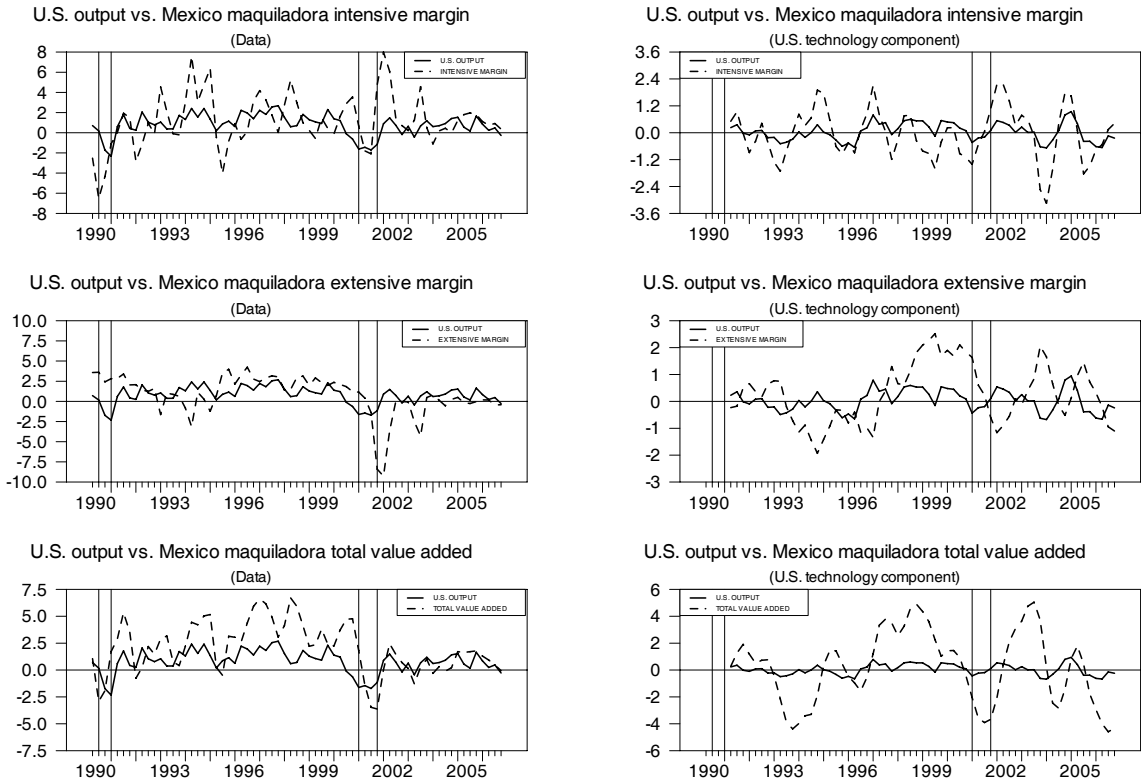


Figure 3. U.S. manufacturing IP vs. offshore production in Mexico (growth rates)

(a) Line charts



(b) Scatterplots

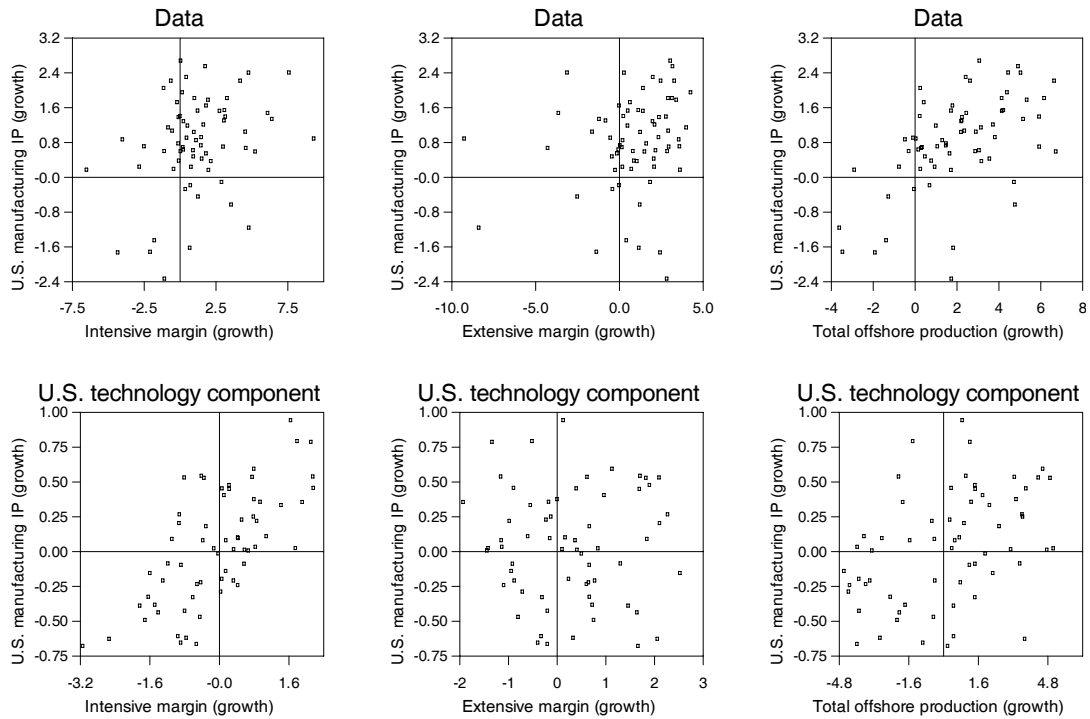
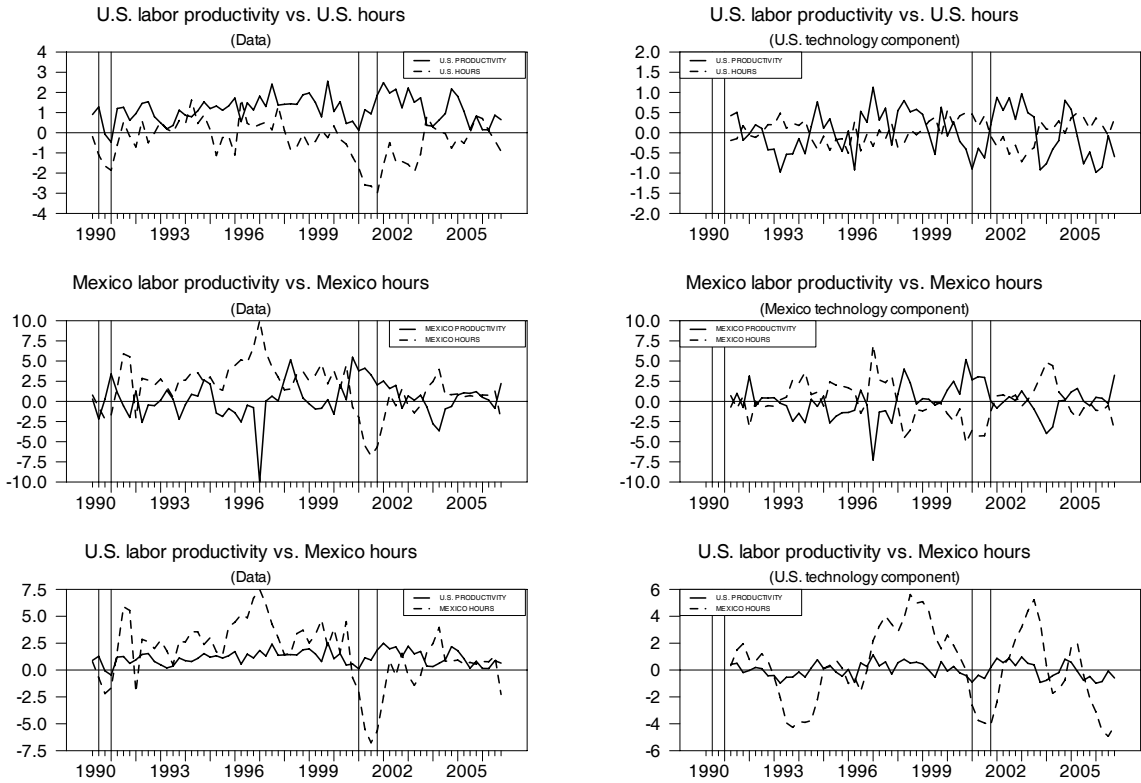


Figure 4. Labor productivity vs. hours worked, U.S. and Mexico (growth rates)

(a) Line charts



(b) Scatterplots

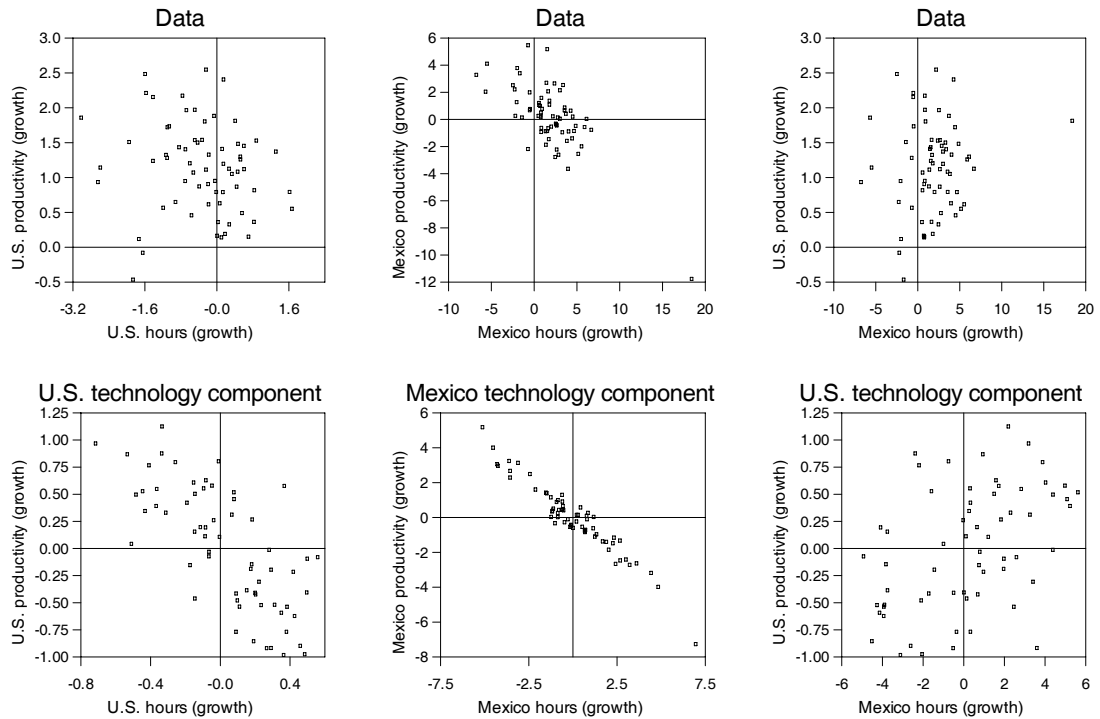


Figure 5. Responses to a U.S.-specific permanent technology shock

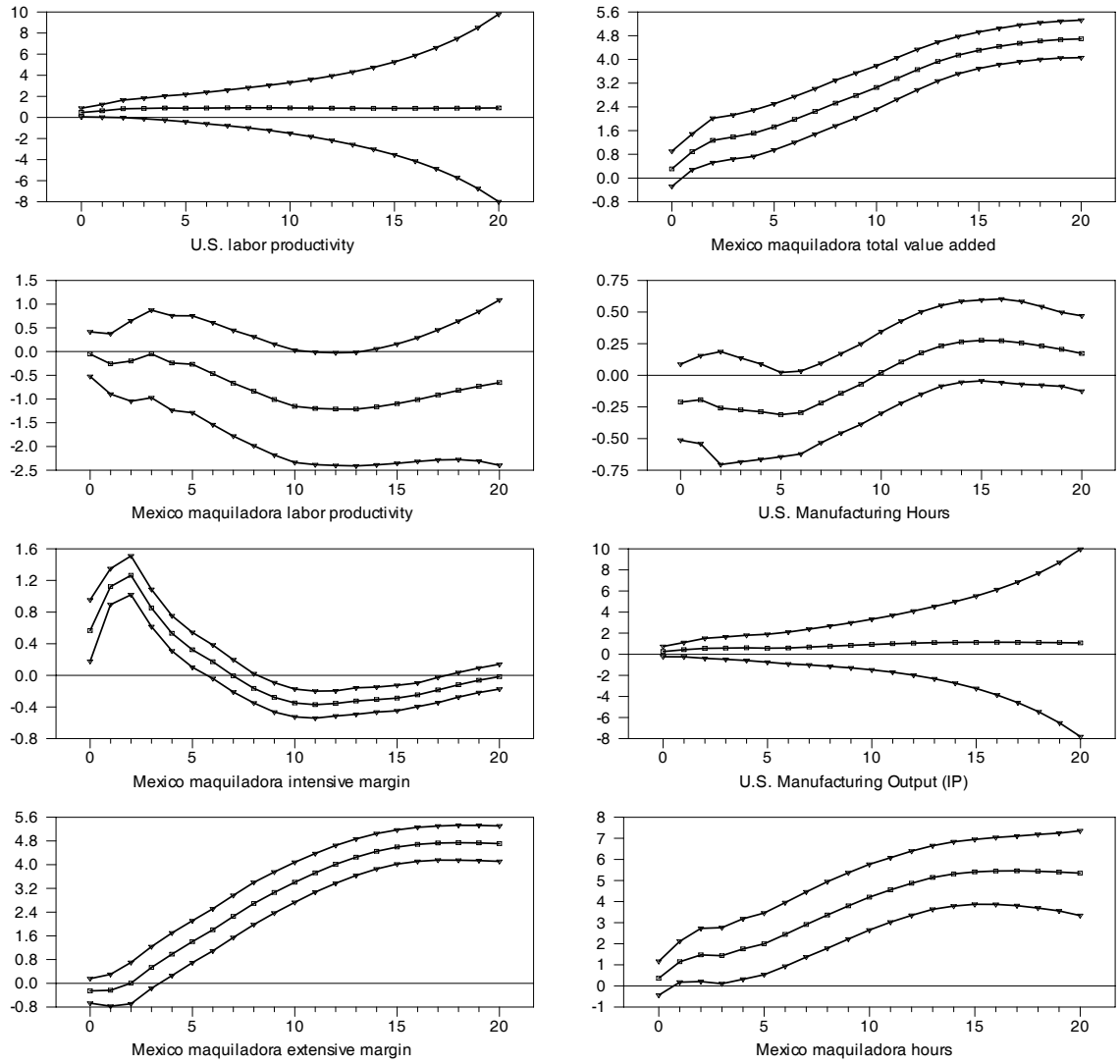
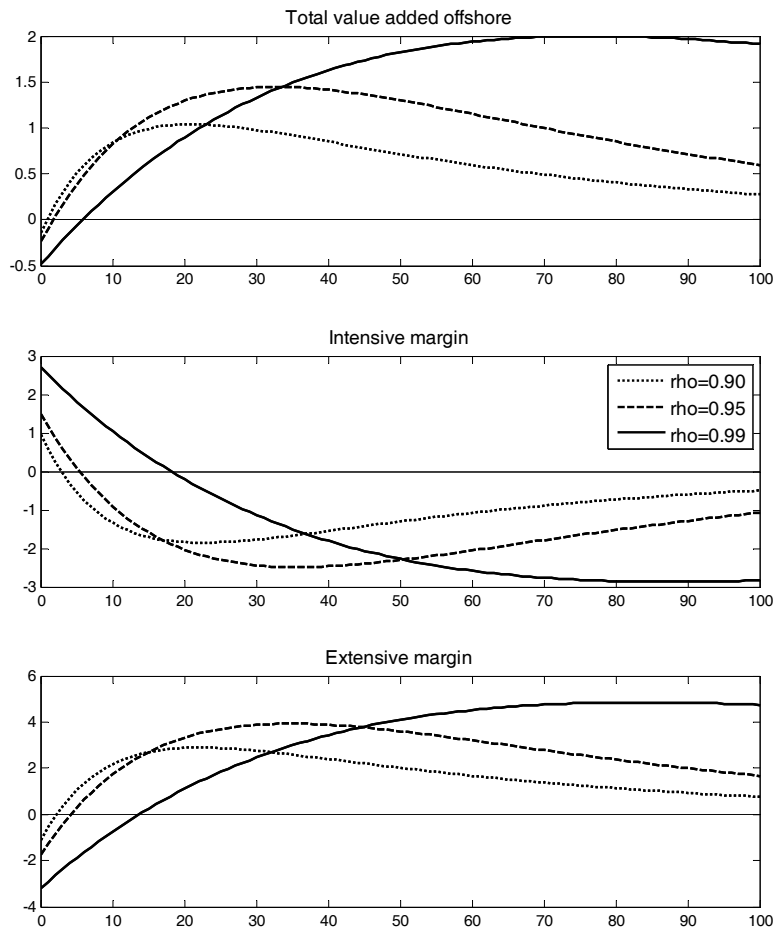


Figure 6. Theoretical impulse responses of offshore production (total value added, the intensive and extensive margins) to a technology shock in the country of origin (North)



Chapter 3

Immigration and the Macroeconomy

*by Federico Mandelman (Federal Reserve Bank of Atlanta) and Andrei Zlate, May 2009*¹

3.1 Introduction

Labor migration is sizable and has a non-negligible economic impact on the economies involved. The number of foreign-born residents is rising worldwide: As much as 12.5 percent of the total U.S. population in 2007 was foreign born, as compared to less than 6 percent in 1980, a pattern which is also visible in several other OECD countries (Grogger and Hanson, 2008). Labor migration also varies over the business cycle. Jerome (1926) documented the procyclical pattern of European immigration into the U.S. during the 19th and early 20th centuries, showing that recessions were associated with drastic declines in immigration flows, while relatively larger inflows occurred during the recovery years.² Adding to this evidence, in Figure 1 we plot the number of apprehensions at the U.S.-Mexico border, which

¹*JEL classification:* F22, F41; *Keywords:* Labor migration, sunk emigration cost, skill heterogeneity, international real business cycles.

²For instance, the number of arrivals into the U.S. declined by 39.1 percent in the recession year of 1908. The same was observed during the recessions of 1876-79, 1894 and 1922. During these years, there were fewer restrictions on European immigration and most of the arrivals into the U.S. were properly documented (O'Rourke and Williamson, 1999).

the existing literature uses as a proxy for attempted illegal crossings into the U.S.,³ along with the U.S./Mexico ratio of real GDP measured in purchasing power parity terms (both series logged and HP-detrended). The chart shows that periods in which the U.S. economy outperformed Mexico's were generally accompanied by an increase in border apprehensions. The correlations in Figure 3(a) confirm this pattern.⁴ Evidence of procyclical immigration also exists for Canada (Sweetman, 2004), the United Kingdom (Gordon et al., 2007) and Australia (RBA, 2007), among other countries.

Immigrants send remittances to their country of origin on a regular basis. Conservative estimates indicate that the remittances sent by emigrants from developing economies back home reached \$240 billion in 2007, which was more than double the amount of 2002.⁵ In 2007, the recorded remittances represented more than 10 percent of the GDP of several receiving countries,⁶ while globally they represented the equivalent of two-thirds of the amount of foreign direct investment received by developing economies, thus becoming a principal component of their total financial inflows.⁷ Just like labor migration, the remittance flows also vary over the business cycle. In Figure 2 we plot the pattern of remittances from the U.S. to Mexico vis-a-vis the relative performance of these economies. The correlations of detrended series in Figure 3(b) confirm that periods with faster U.S. economic growth (or lower Mexican growth) have been associated with larger outflows of remittances to Mexico

³See Hanson (2006) for references. Today's legal immigration involves complicated and long administrative processes which are arguably less related to economic considerations (see Hanson and McIntosh 2007).

⁴Similarly, Hanson and Spilimbergo (1999) find that a 10 percent relative decline in the Mexican real wage has been associated with a 6-8 percent increase in U.S. border apprehensions, with this effect being fully realized within 3 months.

⁵Due to unrecorded flows through formal and informal channels, the actual numbers are believed to be significantly larger than the reported numbers.

⁶Examples include Moldova (36.2%), Honduras (25.6%), Guyana (24.3%) and Jordan (20.3%), Philippines (10%), among many others. Remittances account for roughly 2.5 % of Mexico's GDP (World Bank, 2008).

⁷See Ratha and Xu (2008).

and vice versa. The combined evidence in Figures 1 and 2 highlights the potential insurance role of remittances in smoothing the consumption path of Mexican households whose members reside on both sides of the border.

With this evidence in mind, we examine the business cycle fluctuations of labor migration and remittance flows, as well as their propagation to the rest of the economy. In particular, we study the role of labor migration in explaining the cyclicity of remittance flows over the business cycle. We also study the effect of immigration policy (reflected by the magnitude of immigration barriers) on the volatility of immigration and remittances. To this end, we use a dynamic stochastic general equilibrium (DSGE), two-country, real business cycle model along the lines of Backus, Kehoe and Kydland (1994), in which we allow for endogenous labor migration and remittances. In order to take skill heterogeneity among the native labor into account, we introduce two types of labor in the home economy (skilled and unskilled) while assuming that capital and skilled labor are relative complements as in Krusell et al. (2000), and that the native unskilled and immigrant labor are perfect substitutes as in Borjas et al. (2008). We calibrate the model to match the empirical socio-economic characteristics of labor migration between Mexico and the U.S.

Our methodology bridges the gap between modern international macroeconomic literature and immigration theory. In contrast to our approach, the workhorse model of international macroeconomics assumes that labor is immobile across countries. Instead, labor migration is generally analyzed within formal setups limited to comparisons of long-run positions or to the study of growth dynamics. These models are not suitable for the analysis of immigration dynamics at business cycle frequencies. In our model, the incentive to emigrate depends on the expectation of future earnings at the destination relative to

the country of origin, on the perceived sunk costs of emigration, as well as on the return rate of immigrant labor. This return rate has a non-trivial role, as about 70 percent of undocumented Mexican immigrants in the U.S. tend to return to their country within ten years after their arrival (Reyes, 1997). The sunk cost includes the cost of searching for employment, adjustment to a new lifestyle, transportation expenditures, and in the case of undocumented immigration, the need to hire human smugglers (also known as *coyotes*) as well as the physical risk and legal implications of illegally crossing the border.

In line with the empirical evidence, our model generates immigration and remittance flows that are procyclical with the relative economic performance of the two economies. Both of them are procyclical with output in the destination economy, and countercyclical with output in the country of origin. An additional result consistent with the data is that stricter border enforcement reduces the volatility of the stock of immigrant labor while significantly increasing the volatility of the immigrant wage and remittances.⁸ In the model, the absence of labor mobility restrictions implies that the immigrant labor efficiently exploits the ups and downs of the business cycle. That is, they arrive in large numbers during economic expansions when are most needed, and promptly return to their country of origin when a bad shock hits the destination economy. Higher border enforcement breaks this logic, as the increase in the stock of immigrant labor does not keep up with the increase in labor demand during expansions. Immigrant labor becomes relatively scarce, receives relatively higher wages and sends larger remittances to the foreign economy. In turn, the scarcity of immigrant labor during booms reduces the incentive to accumulate capital, and reduces

⁸Rodriguez-Zamora (2008) shows that the recent increase in border enforcement resulted in less volatile migration inflows and outflows across the US-Mexico border. After growing at double digit rates, remittances drastically fell in the aftermath of the US financial crisis.

the productivity of the destination economy. During recessions, the effect is the opposite. Established immigrants are deterred from returning to their country of origin, bearing in mind that future re-emigration when the destination economy recovers would involve a large sunk cost. Thus, the established immigrant labor remains in the destination economy during recessions, placing additional extra downward pressure on the wage of the native unskilled.

When computing the welfare effects of different enforcement policies, we focus on anticipated deterministic shocks with permanent effects on the balanced growth path, in addition to the stochastic temporary shocks and the associated cyclical considerations. The results indicate that “tightening” the border to constrain the inflow of unskilled labor has a negative impact on welfare in the destination economy, particularly when the complementarity between skilled and unskilled labor is relatively higher, and when the share of the skilled labor in total native labor converges to a relatively higher steady-state level.

This paper is related to existing literature that quantifies the effect of migration in both static (Borjas, 1995; Hamilton and Whalley, 1984; Moses and Letnes, 2004; Walmsley and Winters, 2003) and dynamic frameworks (Djadic, 1987). Our paper is closely related to Klein and Ventura (2007) and Urrutia (1998), who use growth models with endogenous labor movement to assess the welfare effects of removing barriers to labor migration. In the context of DSGE models of international business cycles, our paper is also related to Acosta et al. (2007), Chami et al. (2006) and Durdu and Sayan (2008), who include remittance endowment shocks; to Ghironi and Melitz (2005) and Bilbiie et al. (2006), who introduce an endogenous firm entry mechanism subject to sunk costs; and to Lindquist (2004) and Polgreen and Silos (2006), who use skill heterogeneity and capital-skill complementarity

with two representative households.

The rest of the paper is organized as follows: Section 2 introduces the benchmark model of immigration and remittances; Section 3 presents the alternative model with skill heterogeneity in the destination economy; Section 4 discusses the parameterization; Section 5 describes the model dynamics, providing impulse response and quantitative analysis; Section 6 performs a welfare analysis in the presence of both stochastic and permanent deterministic shocks affecting the sunk immigration costs and the skill composition of the native labor force in the home economy; Section 7 presents the main conclusions.

3.2 Model of Labor Migration with Sunk Costs

The model is representative of a standard two-country setup along the lines of Backus, Kehoe, Kydland (1994, henceforth BKK). Our setup differs from that of BKK in that we use for simplicity log-CRRA preferences and abstract from government purchases and time-to-build in capital formation. Each country specializes in the production of a single (intermediate) good. The final good is a composite of domestic and foreign goods, and can be either consumed or invested.

The novel characteristic of our setup is the presence of labor mobility, as we allow for labor to migrate from the foreign economy to the home one. In the baseline model specification, native and immigrant labor form a CES aggregate which enters, along with capital, in a Cobb-Douglas production function in the home economy. In the model with an alternative production specification (which we describe in the next section) we explore the asymmetric implications of unskilled immigration on native labor at the destination, by

introducing two types of labor in the home economy (skilled and unskilled) in the presence of capital-skill complementarity as in Krusell et al. (2000), while assuming that the native unskilled and immigrant labor are perfect substitutes following the findings in Borjas et al. (2008).

3.2.1 The Home Economy

Supply of Native Labor The representative home household supplies $L_{n,t}$ hours of labor, consumes C_t units of the home composite basket, and invests in physical capital K_t . It maximizes the inter-temporal utility:

$$\max_{\{C_t, L_{n,t}, K_{t+1}\}} E_t \left[\sum_{s=t}^{\infty} \beta^{s-t} U(C_s, L_{n,s}) \right], \quad (3.1)$$

where the period utility function takes the form

$$U(C_t, L_{n,t}) = \ln C_t - \chi \frac{(L_{n,t})^{1+\psi}}{1+\psi}, \quad \chi > 0 \quad (3.2)$$

subject to the constraint:

$$w_{n,t} L_{n,t} + (1 + r_t) K_t \geq C_t + K_{t+1}. \quad (3.3)$$

Parameter $1/\psi \geq 0$ is the Frisch elasticity of labor supply and the inter-temporal elasticity of substitution in labor supply. Following King et al. (1998), we use separable preferences and log-utility from consumption in order to obtain balanced growth path in steady state, i.e. the income and substitution effects of changes in the real wage on hours worked cancel

out and generate constant steady-state labor effort. $w_{n,t}$ is the domestic wage and r_t denotes the return on capital net of depreciation, all expressed in units of the home composite good.

The usual first-order conditions with respect to consumption and labor follow:

$$1 = \beta E_t \left[(1 + r_{t+1}) \frac{C_t}{C_{t+1}} \right], \quad (3.4)$$

$$\frac{w_{n,t}}{C_t} = \chi(L_{n,t})^\psi. \quad (3.5)$$

Production of the Home Intermediate Good

In our baseline model specification, total domestic output is defined by the production of the country specific good, $Y_{h,t}$, which is a Cobb-Douglas function of capital and a CES aggregate of immigrant and native labor:

$$Y_{h,t} = A_t (K_t)^\alpha \left[\gamma^{\frac{1}{\theta}} (L_{i,t})^{\frac{\theta-1}{\theta}} + (1 - \gamma)^{\frac{1}{\theta}} (\zeta L_{n,t})^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta(1-\alpha)}{\theta-1}}, \quad (3.6)$$

where $L_{i,t}$ and $L_{n,t}$ denote immigrant and native labor; γ is the share of immigrant labor income in Home's total labor income; ζ is a parameter that reflects the productivity of native labor relative to that of immigrant labor in steady state; and α is the share of capital in output. Thus, the elasticity of substitution between native labor and capital is the same as that between immigrant labor and capital. The supply of immigrant labor is a decision of the foreign household and will be described later.

Competitive firms maximize profits. Thus, the rental rate of capital (plus depreciation) and the real wages are equal to the marginal products of capital, immigrant and native

labor, respectively:

$$\frac{\partial Y_{h,t}}{\partial K_t} = \alpha \frac{Y_{h,t}}{K_t} = r_t + \delta, \quad (3.7)$$

$$\frac{\partial Y_{h,t}}{\partial L_{i,t}} = (1 - \alpha) \gamma^{\frac{1}{\theta}} (Y_{h,t})^{\frac{1-\theta\alpha}{\theta(1-\alpha)}} (A_t K_t^\alpha)^{\frac{\theta-1}{\theta(1-\alpha)}} (L_{i,t})^{-\frac{1}{\theta}} = w_{i,t}, \quad (3.8)$$

$$\frac{\partial Y_{h,t}}{\partial L_{n,t}} = (1 - \alpha) (1 - \gamma)^{\frac{1}{\theta}} (Y_{h,t})^{\frac{1-\theta\alpha}{\theta(1-\alpha)}} (A_t K_t^\alpha)^{\frac{\theta-1}{\theta(1-\alpha)}} (\zeta)^{\frac{\theta-1}{\theta}} (L_{n,t})^{-\frac{1}{\theta}} = w_{n,t}. \quad (3.9)$$

The country-specific good is used both domestically and offshore:

$$Y_{h,t} = Y_{h1,t} + Y_{h2,t}, \quad (3.10)$$

where $Y_{h1,t}$ denotes the domestic use of the home-specific good, and $Y_{h2,t}$ denotes the exports of the home intermediate good to the foreign economy. Consumption and investment are composites of the home and foreign-specific goods:

$$Y_t = \left[\omega^{\frac{1}{\mu}} (Y_{h1,t})^{\frac{\mu-1}{\mu}} + (1 - \omega)^{\frac{1}{\mu}} (Y_{f1,t})^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}}, \quad (3.11)$$

where $Y_{f1,t}$ denotes the imports of Home from Foreign. The demand functions for the home and foreign-specific goods are:

$$Y_{h1,t} = \omega (p_{h,t})^{-\mu} Y_t, \quad (3.12)$$

$$Y_{f1,t} = (1 - \omega) (p_{f,t} Q_t)^{-\mu} Y_t, \quad (3.13)$$

where $p_{h,t}$ is the price of the home-specific good in units of the home composite good, $p_{f,t}$ is the price of the foreign good in units of the foreign composite good, and Q_t is the

real exchange rate. At the aggregate level, the resource constraint takes into account not only the consumption and investment of the native population (i.e. $C_t + I_t$), but also the consumption of the immigrant labor established in Home:

$$Y_t = C_t + I_t + \frac{L_{i,t}}{\bar{L}^*} C_t^* Q_t. \quad (3.14)$$

We define the consumption of the immigrant labor residing in Home as the amount of foreign consumption C_t^* that is proportional with the share of immigrant labor $L_{i,t}$ in the steady state foreign labor supply \bar{L}^* , expressed in units of the home consumption basket. (The optimization problem of the foreign household with respect to labor supply and emigration will be described shortly.) Finally, the rule of motion for the capital stock is:

$$K_{t+1} = (1 - \delta) K_t + I_t. \quad (3.15)$$

3.2.2 The Foreign Economy

We model labor migration from Foreign to Home. To this end, we introduce cross-country labor mobility with sunk immigration costs: Foreign households have the option to work in the home economy, where wages are higher. However, labor migration from Foreign to Home requires a sunk cost per unit of emigrant labor, a cost which in equilibrium equals the present discounted value of the difference between the future stream of wages obtained as an immigrant in the home economy and the stream of wages obtained in the country of origin.

Location of Labor The foreign household supplies L_t^* units of labor every period. They can either emigrate and work in Home, $L_{i,t}$, or work domestically in Foreign, $L_{f,t}^*$:

$$L_t^* = L_{i,t} + L_{f,t}^*. \quad (3.16)$$

As will be discussed later, we calibrate the sunk migration cost so that the stock of emigrant labor is always lower than the total labor supply in Foreign in any period t , i.e. $0 < L_{i,t} < L_t^*$. The calibration ensures that the immigrant wage in Home is significantly higher than the wage in the country of origin, so that the incentive to emigrate from Foreign to Home exists every period. We also assume that macroeconomic shocks are small enough for this condition to hold every period. For simplicity, we do not allow for labor to flow from Home to Foreign.

Every period foreign workers have the option to emigrate to Home. The time-to-build assumption in place implies that new immigrants start working one period after arriving at the destination. They continue working in the home economy in all subsequent periods, until an exogenous return-inducing shock, which hits them with probability δ_t every period, forces them to return to the country of origin (i.e. the foreign economy). This shock occurs at the end of every time period, and may be linked to issues such as the likelihood of deportation, the impossibility of finding employment in the home economy, or the lack of adaptation to the new country of residence, etc.⁹

⁹This endogenous entry-exogenous exit formulation closely follows the model guidelines in Ghironi and Melitz (2005).

Thus, the rule of motion for the stock of immigrant labor in Home is:

$$L_{i,t} = (1 - \delta_l)(L_{i,t-1} + L_{e,t-1}), \quad (3.17)$$

where $L_{e,t}$ is the amount of new foreign labor that emigrates to Home every period (i.e. a flow variable), and $L_{i,t}$ is the amount of immigrant labor that is located and works in Home every period (i.e. a stock variable).

Household's Problem The representative foreign household has preferences over real consumption and labor effort.¹⁰ It maximizes the inter-temporal utility with respect to total labor L_t^* , emigrant labor $L_{e,t}$ and capital K_{t+1}^* :

$$\max_{\{C_t^*, L_t^*, L_{e,t}, K_{t+1}^*\}} E_t \left[\sum_{s=t}^{\infty} (\beta^*)^{s-t} U(C_s^*, L_s^*) \right]. \quad (3.18)$$

Utility takes the same form as in (3.2), and the budget constraint is:

$$w_t^* (L_t^* - L_{i,t}) + w_{i,t} Q_t^{-1} L_{i,t} + (1 + r_t^*) K_t^* \geq C_t^* + f_e w_{i,t} Q_t^{-1} L_{e,t} + K_{t+1}^*, \quad (3.19)$$

where w_t^* is the wage in the foreign economy and $w_t^* (L_t^* - L_{i,t})$ denotes the total income from hours worked in Foreign. We define $w_{i,t}$ as the immigrant wage earned in Home, so that the immigrants' total labor income expressed in units of the foreign composite good is $w_{i,t} Q_t^{-1} L_{i,t}$. Emigration requires a sunk cost of f_e units of immigrant labor, equal to

¹⁰For simplicity, we do not allow for the possibility in which immigrants are integrated into the societies where they reside. Here immigrants and natives remain as separate entities when maximizing utility. We believe that our assumption is reasonable given our emphasis in business cycle implications. In addition, the fact that return migration is sizable (as explained in the introduction) and immigrants' cultural integration is limited, provides support to our premise.

$f_e w_{i,t} Q_t^{-1}$ units of the foreign consumption basket. Finally, r_t^* is the return on foreign capital net of depreciation.

It is useful to re-write the constraint as:

$$w_t^* L_t^* + d_t L_{i,t} + (1 + r_t^*) K_t^* \geq C_t^* + f_e w_{i,t} Q_t^{-1} L_{e,t} + K_{t+1}^*, \quad (3.20)$$

where d_t is the difference between the immigrant wage in Home and the wage in the country of origin at time t , expressed in units of the foreign consumption basket:

$$d_t = w_{i,t} Q_t^{-1} - w_t^*. \quad (3.21)$$

Potential emigrants face a trade-off between the sunk migration cost, $f_e w_{i,t} Q_t^{-1}$, and the present discounted value of the difference between the streams of future wages at the destination, $w_{i,t} Q_t^{-1}$, and in the country of origin, w_t^* , expressed in units of the foreign composite good. Using the new budget constraint and the law of motion for the stock of immigrant labor, $L_{i,t} = (1 - \delta_l)(L_{i,t-1} + L_{e,t-1})$, the optimization with respect to new emigrant labor $L_{e,t}$ every period implies:

$$f_e w_{i,t} Q_t^{-1} = \sum_{s=t+1}^{\infty} [\beta^*(1 - \delta_l)]^{s-t} E_t \left[\left(\frac{C_t^*}{C_s^*} \right) d_s \right], \quad (3.22)$$

which shows that, in equilibrium, the sunk emigration cost equals the present discounted gain from emigration, measured as the difference between the future expected wages at the destination and in the country of origin, expressed in units of the foreign composite good.

Production of the Foreign Intermediate Good Foreign production is a Cobb-Douglas function of non-emigrant labor, $L_{f,t}^*$, and capital, K_t^* . Following BKK, the resulting foreign-specific intermediate good, $Y_{f,t}$, can be either used domestically, $Y_{f2,t}$, or exported to the Home economy, $Y_{f1,t}$:

$$Y_{f,t} = A_t^* (K_t^*)^{\alpha^*} (L_{f,t}^*)^{1-\alpha^*}, \quad (3.23)$$

$$Y_{f,t} = Y_{f1,t} + Y_{f2,t}. \quad (3.24)$$

The foreign composite good, Y_t^* , incorporates amounts of both the foreign-specific intermediate good, $Y_{f2,t}$, and the home-specific imported good, $Y_{h2,t}$:

$$Y_t^* = \left[\omega^{*\frac{1}{\mu}} (Y_{f2,t})^{\frac{\mu-1}{\mu}} + (1 - \omega^*)^{\frac{1}{\mu}} (Y_{h2,t})^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}}. \quad (3.25)$$

This final good composite can be consumed by the foreign resident labor (i.e. as opposed to the foreign emigrant labor), can be invested in physical capital, and can be used for investment in new emigration (i.e. to cover the sunk costs required to send new emigrant labor abroad):

$$Y_t^* = \left(1 - \frac{L_{i,t}}{L^*} \right) C_t^* + I_t^* + f_e w_{i,t} Q_t^{-1} L_{e,t} \quad (3.26)$$

Finally, capital accumulation is described by:

$$K_{t+1}^* = (1 - \delta^*) K_t^* + I_t^*. \quad (3.27)$$

Optimality Conditions Households' optimization problem delivers a typical Euler equation and pins down the total labor effort:

$$1 = \beta E_t \left[(1 + r_{t+1}^*) \frac{C_t^*}{C_{t+1}^*} \right], \quad (3.28)$$

$$\frac{w_t^*}{C_t^*} = \chi^* (L_t^*)^\psi, \quad (3.29)$$

The demand functions for the home and foreign-specific goods are:

$$Y_{f2,t} = \omega^* (p_{f,t})^{-\mu} Y_t^*, \quad (3.30)$$

$$Y_{h2,t} = (1 - \omega^*) \left(\frac{p_{h,t}}{Q_t} \right)^{-\mu} Y_t^*, \quad (3.31)$$

where $p_{f,t}$ and $\frac{p_{h,t}}{Q_t}$, respectively, are the price of the foreign-specific and home-specific good, both expressed in units of the foreign consumption basket.

In turn, the net return on capital and local wages are respectively determined by the marginal product of capital and labor:

$$r_t^* = \alpha^* \frac{Y_{f,t}}{K_t^*} - \delta^*, \quad (3.32)$$

$$w_t^* = (1 - \alpha^*) \frac{Y_{f,t}}{L_{f,t}^*}. \quad (3.33)$$

3.2.3 Financial Integration

We introduce financial integration by assuming that: (1) International asset markets are incomplete, and households in each country issue risk-free bonds denominated in their own currency, as in Ghironi and Melitz (2005); (2) Each type of bond provides a real return

denominated in units of that country's consumption basket. (3) In order to avoid the non-stationarity of net foreign assets we introduce quadratic costs of adjustment for bond holdings, a tool which allows us to pin down the steady state and also to ensure stationarity.

The infinitely-lived representative agent maximizes the inter-temporal utility subject to the constraint:

$$\begin{aligned} w_t L_t + (1 + r_t^k) K_t + (1 + r_t^b) B_{h,t} + (1 + r_t^{b*}) Q_t B_{f,t} + T_t \\ \geq C_t + K_{t+1} + B_{h,t+1} + \frac{\pi}{2} (B_{h,t+1})^2 + Q_t B_{f,t+1} + \frac{\pi}{2} Q_t (B_{f,t+1})^2, \end{aligned} \quad (3.34)$$

where r_t^k is the rental rate of capital in Home; r_t^b and r_t^{b*} are the rates of return of the home and foreign bonds; $(1 + r_t^b) B_{h,t}$ and $(1 + r_t^{b*}) Q_t B_{f,t}$ are the principal and interest income from holdings of the home and foreign bonds; $\frac{\pi}{2} (B_{h,t+1})^2$ and $\frac{\pi}{2} Q_t (B_{f,t+1})^2$ are the cost of adjusting holdings of the home and foreign bonds, respectively; T_t is the fee rebate.¹¹ We add the two Euler equations for bonds to the baseline model:

$$1 + \pi B_{h,t+1} = \beta(1 + r_{t+1}^b) E_t \left[\frac{C_t}{C_{t+1}} \right], \quad (3.35)$$

$$1 + \pi B_{f,t+1} = \beta(1 + r_{t+1}^{b*}) E_t \left[\frac{Q_{t+1}}{Q_t} \frac{C_t}{C_{t+1}} \right]. \quad (3.36)$$

¹¹ π is positive to avoid non-stationarity of the stock of liabilities, but is set close to zero (0.0025) to avoid altering the high-frequency dynamics of the model. In addition, following Bodenstein (2008), later we will pick a sufficiently high value for the trade elasticity of substitution, μ , to avoid the possibility of multiple equilibria.

With trade in bonds, the budget constraint of the foreign household becomes:

$$\begin{aligned}
& w_t^* (L_t^* - L_{i,t}) + w_{i,t} Q_t^{-1} L_{i,t} + (1 + r_t^{k*}) K_t^* + (1 + r_t^b) Q_t^{-1} B_{h,t}^* + (1 + r_t^{b*}) B_{f,t}^* + T_t^* \\
& \geq C_t^* + f_e w_{i,t} Q_t^{-1} L_{e,t} + K_{t+1}^* + Q_t^{-1} B_{h,t+1}^* + \frac{\pi}{2} Q_t^{-1} (B_{h,t+1}^*)^2 + B_{f,t+1}^* + \frac{\pi}{2} (B_{f,t+1}^*)^2,
\end{aligned} \tag{3.37}$$

and the corresponding Euler equations for bonds are:

$$1 + \pi B_{h,t+1}^* = \beta^* (1 + r_{t+1}^b) E_t \left[\frac{Q_t}{Q_{t+1}} \frac{C_t^*}{C_{t+1}^*} \right], \tag{3.38}$$

$$1 + \pi B_{f,t+1}^* = \beta^* (1 + r_{t+1}^{b*}) E_t \left[\frac{C_t^*}{C_{t+1}^*} \right]. \tag{3.39}$$

The market clearing conditions for bonds are:

$$B_{h,t+1} + B_{h,t+1}^* = 0, \tag{3.40}$$

$$B_{f,t+1} + B_{f,t+1}^* = 0. \tag{3.41}$$

Thus, financial integration through trade in country-specific bonds adds 6 variables ($B_{h,t}$, $B_{f,t}$, $B_{h,t}^*$, $B_{f,t}^*$, r_t^b and r_t^{b*}) and 6 equations (3.35, 3.36, 3.38, 3.39, 3.40 and 3.41) to the baseline model with financial autarky.

3.2.4 Trade Balance and Remittances

From a theoretical standpoint, we define workers' remittances, $\bar{\Xi}_t$, as the difference between (a) the immigrant labor income and (b) the immigrant labor's share in foreign consumption,

measured as the amount of foreign consumption that is proportional with the share of immigrant labor in the steady-state foreign labor supply, expressed in units of the home consumption basket:

$$\Xi_t = w_{i,t}L_{i,t} - \frac{L_{i,t}}{L^*}C_t^*Q_t. \quad (3.42)$$

Thus, the current account balance, measured in units of the home composite good, is:

$$CA_t = p_{h,t}Y_{h2,t} - p_{f,t}Q_tY_{f1,t} - \Xi_t. \quad (3.43)$$

Under financial autarky, the balanced current account condition, $CA_t = 0$, implies that the trade balance, $TB_t = p_{h,t}Y_{h2,t} - p_{f,t}Q_tY_{f1,t}$, must equal the amount of remittances, Ξ_t . Here remittances act as a substitute for contingent claims in smoothing income flows in the absence of financial integration.¹²

Under financial integration, we replace the balanced current account condition ($TB_t - \Xi_t = 0$) from the model with financial autarky with the expression for the balance of international payments:

$$(p_{h,t}Y_{h2,t} - p_{f,t}Q_tY_{f1,t}) + (r_t^b B_{h,t} + r_t^{b*} Q_t B_{f,t}) - \Xi_t = (B_{h,t+1} - B_{h,t}) + Q_t (B_{f,t+1} - B_{f,t}) \quad (3.44)$$

which shows that the current account balance (i.e. the trade balance plus financial invest-

¹²It is useful to show that, using the resource constraint $Y_t = p_{h,t}Y_{h1,t} + p_{f,t}Q_tY_{f1,t} = C_t + I_t + \frac{L_{i,t}}{L^*}C_t^*Q_t$, we can re-write the home GDP expressed in units of the home-specific good as $p_{h,t}Y_{h,t} = C_t + I_t + \frac{L_{i,t}}{L^*}C_t^*Q_t + TB_t$. Similarly, using that $Y_t^* = p_{h,t}Q_t^{-1}Y_{h2,t} + p_{f,t}Y_{f2,t} = \left(1 - \frac{L_{i,t}}{L^*}\right)C_t^* + I_t^* + f_e w_{i,t}Q_t^{-1}L_{e,t}$, we can write the foreign GDP expressed in units of the foreign-specific good as $p_{f,t}Y_{f,t} = \left(1 - \frac{L_{i,t}}{L^*}\right)C_t^* + I_t^* + f_e w_{i,t}Q_t^{-1}L_{e,t} - Q_t^{-1}TB_t$.

ment income minus remittances) must equal the negative of the financial account balance (i.e. the change in bond holdings).

3.3 Alternative Model Specification (Skill Heterogeneity)

We allow for skill heterogeneity in Home by introducing two types of native labor: skilled and unskilled. We also assume that the foreign labor is relatively unskilled and can migrate to Home, where it becomes a perfect substitute for the native unskilled labor, as in Borjas et al. (2008). Capital and native skilled labor are relative complements, whereas capital and unskilled labor (i.e. immigrant and native) are relative substitutes, as in Krusell et al. (2000).

Native Labor Supply with Two Representative Households While the description of the foreign economy remains identical, the home economy now includes a continuum of two types of infinitely-lived households that supply units of skilled and unskilled labor, as in Lindquist (2004) and Polgreen and Silos (2006). Every period t , each of the two representative households consumes $c_{j,t}$ units the home consumption basket and supplies $l_{j,t}$ units of labor, where subscript $j \in \{s, u\}$ denotes skilled and unskilled labor, respectively. Thus, the planner maximizes the weighted sum of utilities for the two representative households:

$$\max_{\{c_{s,t}, l_{s,t}, c_{u,t}, l_{u,t}, K_{t+1}\}} \sum_{t=0}^{\infty} \beta^{s-t} \{ \phi s U(c_{s,t}, l_{s,t}) + (1 - \phi)(1 - s) U(c_{u,t}, l_{u,t}) \}, \quad (3.45)$$

where utility takes the log-CRRA form as in (3.2), and the constraint is:

$$w_{s,t}L_{s,t} + w_{u,t}L_{u,t} + (1 + r_t)K_t \geq C_{s,t} + C_{u,t} + K_{t+1}, \quad (3.46)$$

where s denotes the fraction of skilled households and $1 - s$ is the fraction of unskilled households in the total population; ϕ and $1 - \phi$ are the weights of the utility of skilled and unskilled households, respectively, in the objective function of the planner. $L_{s,t} = sl_{s,t}$ and $L_{u,t} = (1 - s)l_{u,t}$ are the aggregate amounts of skilled and unskilled labor which firms hire at the equilibrium wages $w_{s,t}$ and $w_{u,t}$, respectively. $C_{s,t} = sc_{s,t}$ and $C_{u,t} = (1 - s)c_{u,t}$ are the aggregate consumptions of the skilled and unskilled households.

The maximization problem for the two representative agents generates the usual first-order conditions:

$$\frac{\phi}{c_{s,t}} = \frac{1 - \phi}{c_{u,t}} = \zeta_t, \quad (3.47)$$

$$1 = \beta E_t \left[(1 + r_{t+1}^*) \frac{\zeta_{t+1}}{\zeta_t} \right], \quad (3.48)$$

$$\frac{w_{s,t}}{c_{s,t}} = \frac{\chi_s}{s} (l_{s,t})^{\psi_s}, \quad (3.49)$$

$$\frac{w_{u,t}}{c_{u,t}} = \frac{\chi_u}{(1 - s)} (l_{u,t})^{\psi_u}. \quad (3.50)$$

where $\chi_j, \psi_j, j \in \{s, u\}$ represent weights in the utility function and the inverse of the Frisch elasticity of skilled and unskilled labor supply.

Production of the Home Intermediate Good In the alternative specification, production function is a nested CES aggregate:

$$Y_{h,t} = A_t \left\{ \gamma^{\frac{1}{\theta}} (\Upsilon_{1,t})^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} (\Upsilon_{2,t})^{\frac{\theta-1}{\theta}} \right\}^{\frac{\theta}{\theta-1}}, \quad (3.51)$$

of the following components:

$$\Upsilon_{1,t} = L_{i,t} + L_{u,t}, \quad (3.52)$$

$$\Upsilon_{2,t} = \left[\lambda^{\frac{1}{\eta}} (K_t)^{\frac{\eta-1}{\eta}} + (1-\lambda)^{\frac{1}{\eta}} (\zeta L_{s,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \quad (3.53)$$

where $\Upsilon_{1,t}$ is a function in which the unskilled immigrant and native labor enter as perfect substitutes; $\Upsilon_{2,t}$ is a CES function of capital and skilled native labor; γ is the fraction of unskilled labor in output; $\lambda/(1-\gamma)$ is the share of capital in output. Finally, $\theta > 0$ governs the elasticity of substitution between skilled and unskilled labor, which is the same as the elasticity of substitution between capital and unskilled labor; $\eta > 0$ is the elasticity of substitution between capital and skilled labor. Following Krusell et al. (2000), we restrict $\theta > \eta$ under the assumption of capital-skill complementarity.

The profit maximization problem of firms generates the following optimality conditions:

$$\frac{\partial Y_{h,t}}{\partial K_t} = \xi_1 (A_t)^{\frac{\theta-1}{\theta}} (Y_{h,t})^{\frac{1}{\theta}} (\Upsilon_{2,t})^{\frac{\theta-\eta}{\eta\theta}} (K_t)^{-\frac{1}{\eta}} = r_t + \delta, \quad (3.54)$$

$$\frac{\partial Y_{h,t}}{\partial L_{i,t}} = \frac{\partial Y_{h,t}}{\partial L_{u,t}} = (A_t)^{\frac{\theta-1}{\theta}} \left(\gamma \frac{Y_{h,t}}{L_{i,t} + L_{u,t}} \right)^{\frac{1}{\theta}} = w_{u,t}, \quad (3.55)$$

$$\frac{\partial Y_{h,t}}{\partial L_{s,t}} = \xi_2 (A_t)^{\frac{\theta-1}{\theta}} (Y_{h,t})^{\frac{1}{\theta}} (\Upsilon_{2,t})^{\frac{\theta-\eta}{\eta\theta}} (\zeta)^{\frac{\eta-1}{\eta}} (L_{s,t})^{-\frac{1}{\eta}} = w_{s,t}, \quad (3.56)$$

where $\xi_1 = (1 - \gamma)^{\frac{1}{\theta}} \lambda^{\frac{1}{\eta}}$ and $\xi_2 = (1 - \gamma)^{\frac{1}{\theta}} (1 - \lambda)^{\frac{1}{\eta}}$.

The rest of the economy is described by the equations of the baseline specification model outlined in the previous section. The only exception is the resource constraint in the home economy, which becomes:

$$Y_t = C_{s,t} + C_{u,t} + I_t + \frac{L_{i,t}}{L^*} C_t^* Q_t \quad (3.57)$$

3.4 Parameterization

We use the standard quarterly calibration from BKK: $\mu = 1.5$ is the elasticity of substitution between the home and foreign-specific goods in the composite basket of both countries; $\alpha = 0.33$ is the share of capital in output; $\delta = 0.025$ is the depreciation rate of the capital stock; $\omega = \omega^* = 0.85$ reflects the degree of home bias in each economy; $\psi = \psi^* = 0.33$ is the inverse of the elasticity of labor supply. In addition, we set the quarterly return rate for the established immigrant labor $\delta_l = 0.07$, which reflects the findings in Reyes (1997) that approximately 50 percent of the undocumented Mexican immigrants return to their country of origin within two years after their arrival in the U.S. (which corresponds to a quarterly exit rate of 0.0635), and that 65 percent of them return within four years after their arrival (i.e. quarterly exit rate of 0.0830).¹³

Baseline Model Calibration For the baseline model with symmetric elasticity of substitution between capital and each type of labor (native and immigrant) and interna-

¹³Using the information that 35 percent of the undocumented Mexican immigrants are still in the U.S. four years after their arrival, we compute the quarterly exit rate as $(1 - \delta_{l,4y})^{16} = 0.35$.

tional trade in bonds, the calibration parameters are described in Table 1. We are left with four parameters to calibrate: γ , θ , ζ and f_e . To this end, we choose four empirical moments that the model should match within reasonable limits in steady state: (1) The share of Mexico’s labor force residing in the U.S. is 10 percent (Hanson, 2006); (2) Remittances represented the equivalent of 2.5 percent of Mexico’s GDP in 2004 (Bank of Mexico, 2004)¹⁴; (3) The ratio between the average wages of U.S. native and Mexican immigrant labor is 2.1¹⁵; (4) The U.S.-Mexico ratio of GDP per capita expressed in terms of purchasing power parity is approximately 3.3, according to IMF’s World Economic Outlook data. To this end, we set $\gamma = 0.08$ (the share of immigrant labor in total labor income), $\zeta = 6.2$ (the relative productivity of native vs. immigrant labor), $\theta = 1.30$ (the elasticity of substitution between native and immigrant labor¹⁶), and $f_e = 4.7$ (the sunk cost of labor migration).¹⁷ Given the key role of the degree of complementarity between native and immigrant labor, we perform robustness checks with low and high substitutability between immigrant and native workers, $\theta = 0.5$ and $\theta = 2.5$.

¹⁴The model generates a more conservative estimate (1 percent) compared to the 2.5 percent recorded in 2004 (Bank of Mexico, 2004), as remittances to Mexico more than doubled between 1997 and 2004 (Hernández-Coss, 2005).

¹⁵For the immigrant wage we use the average hourly wages for immigrant Mexican males in the U.S. (28 to 32 years of age, with 9 to 11 years of schooling completed) provided by Hanson (2006); we also compute the weighted average hourly wage of the U.S. native labor using data from the U.S. Census Bureau (2007).

¹⁶We take the estimate of the elasticity of substitution between skilled and unskilled labor (1.26) under the symmetric model setup in Krusell et al. (2000) as a benchmark for the value of θ in our baseline model.

¹⁷Relative to these targets, the baseline model with trade in bonds generates: (1) the steady state share of immigrant labor in Foreign’s total is $\frac{L_i}{L^*} = 0.1$; (2) the ratio between the native and immigrant labor is $\frac{w_n}{w_i} = 1.63$; (3) remittances represent the equivalent of 1.5 percent of the foreign GDP; (4) the GDP ratio between Home and Foreign is 2.3.

Table 1. Baseline model calibration

$\gamma = 0.08$	Share of immigrant labor in total labor income
$\zeta = 6.2$	Relative productivity of native vs. immigrant labor
$\theta = 1.3$	Elasticity of substitution between native and immigrant labor
$f_e = 4.7$	Sunk cost of labor migration

Alternative Model Calibration For the alternative model with two types of native labor in Home (skilled and unskilled), in which native unskilled and immigrant labor are perfect substitutes, the calibration is summarized in Table 2. We define the pool of native unskilled labor to include the adult population without a high school degree; using data from the U.S. Census Bureau, we set the share of unskilled labor at $(1 - s) = 0.08$.

We choose values for parameters $\tilde{\gamma}$, $\tilde{\theta}$, $\tilde{\eta}$, $\tilde{\zeta}$ and \tilde{f}_e so that the alternative model with trade in bonds comes reasonably close to replicating a set of five empirical moments from the U.S. and Mexico in steady state: (1) The share of Mexico’s labor force residing in the U.S. is $\frac{L_i}{L^*} = 0.1$ (Hanson, 2006). (2) Remittances represent the equivalent of 2.5 percent of Mexico’s GDP (compared to which the model generates the more conservative estimate of 1.5 percent); (3) The ratio between the wages of the native skilled and unskilled labor in the U.S. is 2.2 (and $\frac{w_s}{w_u} = 2.2$ in the model).¹⁸ (4) Controlling for age and educational attainment, the ratio between the hourly wage of Mexican immigrants in the U.S. and the corresponding wage in Mexico expressed in terms of purchasing power parity is 3.64

¹⁸We take the weighted average of hourly earnings for the U.S. skilled labor (i.e. high school degree or more), as well as for the U.S. unskilled labor (i.e. without a high school degree) using data provided by the U.S. Census Bureau (2006, 2007). We divide the sample into four groups: (a) no high school degree; (b) completed high school; (c) some college or associate’s degree; and (d) bachelor’s degree or higher. Then we take the average of the respective earnings weighted by their share in the total population.

(compared to which the model generates $\frac{w_i}{Qw^*} = 1.9$, enough to maintain the labor migration incentive);¹⁹ (5) The U.S.-Mexico share of GDP per capita expressed in purchasing power parity terms is approximately 3.3, according to IMF’s World Economic Outlook data (vs. 3.5 in the model). To this end, we choose $\tilde{\gamma} = 0.1$, $\tilde{\theta} = 1.30$, $\tilde{\eta} = 1.07$, $\tilde{\zeta} = 3.1$ and $\tilde{f}_e = 5.4$. As already discussed, we base the assumption that $\tilde{\theta} > \tilde{\eta}$ on the findings of Krusell et al. (2000) that skilled labor and capital are relative complements, whereas skilled and unskilled labor are relative substitutes.²⁰

Table 2. Alternative model calibration

$s = 0.92$	Share of Home skilled in total households
$\tilde{\gamma} = 0.1$	Share of native + immigrant unskilled in GDP
$\tilde{\lambda} = \alpha/(1 - \tilde{\gamma})$	Share of capital in GDP
$\tilde{\theta} = 1.30$	Elasticity of substitution, capital vs. unskilled labor
$\tilde{\eta} = 1.07$	Elasticity of substitution, capital vs. skilled labor
$\tilde{\zeta} = 3.1$	Relative productivity of native vs. immigrant labor
$\tilde{f}_e = 5.4$	Sunk cost of labor migration
$\phi = 0.688$	Weight on the utility of skilled labor

Finally, we set the weight on the utility of representative skilled household $\phi = 0.688$,

¹⁹We build this ratio using wage data provided in Hanson (2006) for (1) the hourly wage of the recent Mexican immigrants in the U.S., and (2) the hourly wage of those of similar age and educational attainment that reside in Mexico (i.e. males between 28-32 years of age with 9 to 11 years of schooling), adjusted for purchasing power parity. The wage ratios for other age and educational attainment groups are similar (see Hanson, 2006).

²⁰We take the estimates for the elasticity of substitution between skilled and unskilled labor (1.67) and that for capital and skilled labor (0.67) from the specification with capital-skill complementarity in Krusell et al. (2000) as benchmarks for the values of $\tilde{\theta}$ and $\tilde{\eta}$ in our alternative model with skill heterogeneity.

so that the consumption ratio for the home representative skilled and unskilled households matches the corresponding wage ratio, $\frac{c_s}{c_u} = \frac{w_s}{w_u} = 2.2$. We base our assumption on the findings of Krueger and Perri (2007) and Attanasio and Davis (1996) that differences in the consumption of population groups with different levels of educational attainment (e.g. skilled and unskilled) closely reflect the income differences between the respective groups.

3.5 Results

3.5.1 Impulse Response Analysis

To illustrate the workings of the model, we consider the response paths of key variables (percent deviations from steady state) to unanticipated productivity innovations in the home economy for both the baseline and the alternative model (Figures 4-7). We assume that productivity follows a first-order autoregressive process that persists at the rate of 0.95 per quarter. We report the responses of the key variables, measured as the percent deviation from steady state in each quarter after the initial shock, to transitory changes in productivity.

Baseline Model with Financial Autarky As shown in Figure 4, following a transitory one percent increase in productivity in Home, the increase in the immigrant wage premium (d) encourages the entry of new immigrants (L_e), entry which is however dampened by the sunk emigration cost. The immigrant wage premium and immigrant entry persist above their steady-state levels after the initial shock, so that the stock of established immigrant labor (L_i) adjusts gradually over time. The stock of immigrant labor increases by more in the economy with the relatively low sunk immigration cost ($f_e = 2.0$, dotted line).

In contrast, immigrant labor becomes relatively more scarce during booms in Home in the scenario with the higher sunk cost ($f_e = 4.7$, continuous line), thus causing the immigrant wage to increase by more. Therefore, as foreign households attempt to smooth consumption across members residing in both countries, remittances increase by more in the model with the higher sunk immigration cost. The results indicate that a more restrictive immigration policy and higher immigration barriers enhance the volatility of the immigrant wage and remittances.

In the foreign economy, output declines by less in the scenario with the higher sunk cost of immigration. The result is due to the larger amount of resident labor that is forced to remain in Foreign, which in turn dampens the wage increase and enhances the accumulation of physical capital in Foreign.

Baseline Model with High Complementarity Due to the complementarity between capital and immigrant labor, the higher sunk cost of immigration dampens investment and output growth in Home relative to the scenario with the relatively low sunk cost. Although small in the baseline calibration, the effect increases with the complementarity between the native and immigrant labor. The impulse responses in Figure 5 show that a higher complementarity between the two types of labor ($\theta = 0.5$) relative to the baseline calibration ($\theta = 1.5$) makes the barriers to immigration more harmful for the home economy. The higher complementarity dampens the increase in the demand for native labor and also capital accumulation in Home, which causes a relatively lower increase in home output, native wage and consumption than in the baseline calibration case.²¹

²¹The case of high immigration barriers and high complementarity between the native and immigrant labor delivers a paradoxical behavior of the real exchange rate and of the terms of trade. Although the scenario

Baseline Model with Financial Integration The response paths are similar for the baseline model with international trade in bonds (Figure 6). In this case, one-period risk-free bonds constitute an additional instrument - other than remittances - that foreign households can use to smooth their inter-temporal consumption path. That is, from a risk sharing perspective, foreign households have the option to lend offshore as an alternative to investing in emigration. Following a transitory one percent increase in home productivity, financial integration allows capital to migrate towards the economy with a relatively high rate of return (Home), whose trade balance becomes negative. In turn, Home becomes relatively more capital intensive, which improves the productivity of labor and encourages more immigration over the business cycle (i.e. the entry and the stock of immigrant labor increase by more for $f_e = 2.0$, dotted line) relative to the case with financial autarky (depicted in Figure 4).

Alternative Model with Financial Integration The alternative model with financial integration generates results that suggest a similar link between immigration flows and remittances. Following a one percent transitory increase in home productivity, the adjustment in the stock of established immigrant labor is faster and larger in the economy with the lower immigration cost. In turn, the greater flexibility of the supply of immigrant labor during booms leads to a lower increase in the immigrant wage and the amount of remittances.

with high barriers to immigration generates a relatively more scarce home output and more abundant foreign output (because a larger share of foreign labor remains in the country of origin, as explained above) relative to the scenario with low immigration costs, higher remittances improve the purchasing power of residents in Foreign, that have a home bias towards the foreign good. In turn, this leads to an increase in the relative price of foreign output, so that the real exchange rate Q increases by more (i.e. the real exchange rate of Home depreciates by more) than in the case with low sunk cost.

In the presence of skill heterogeneity in Home, the results highlight the asymmetric effect of unskilled immigration on the native labor. During booms, the relatively quick adjustment in the stock of immigrant labor in the scenario with a lower immigration cost dampens the increase in the native unskilled wage, as the native unskilled and immigrant unskilled labor are perfect substitutes. Conversely, during recessions in Home, the sharper decline in the stock of immigrant labor allows for a smaller decline in the wage of native unskilled labor. Thus, a more flexible immigration policy reduces the volatility of wages for the native labor types that are close substitutes with immigrant labor.

3.5.2 Theoretical Moments

In order to test the empirical relevance of our model, we compute the second moments of migration flows and remittances generated by the baseline and alternative models with trade in bonds, and contrast them to the corresponding empirical moments. We show that both models succeed qualitatively in replicating the key cyclical characteristics of labor migration and remittances which we document using data for the U.S. and Mexico.

As in the standard international real business cycles literature, we assume that productivity follows an autoregressive bivariate process:

$$\begin{bmatrix} \log A_t \\ \log A_t^* \end{bmatrix} = \begin{bmatrix} \rho_A & \rho_{AA^*} \\ \rho_{A^*A} & \rho_{A^*} \end{bmatrix} \begin{bmatrix} \log A_{t-1} \\ \log A_{t-1}^* \end{bmatrix} + \begin{bmatrix} \xi_t \\ \xi_t^* \end{bmatrix}, \quad (3.58)$$

Following Heathcote and Perri (2002), we estimate its parameters using the seemingly unrelated regression (SURE) method.²² To this end, we use the Solow residual as a measure

²²Typically, international real business cycle models are solved assuming that total factor productivity

for aggregate productivity in the U.S. and Mexico, computed from quarterly data on GDP, the capital stock and employment (measured as the number of workers) for the interval between 1987:1 and 2003:2.²³

Our estimates for the transition matrix of the productivity process \mathbf{A} and for the variance-covariance matrix Σ are given below (with standard errors in parentheses):

$$\mathbf{A} = \begin{bmatrix} 0.996 & 0.003 \\ (0.014) & (0.015) \\ 0.049 & 0.951 \\ (0.040) & (0.040) \end{bmatrix}, \Sigma = \begin{bmatrix} 0.0050939^2 & 0.00001898 \\ 0.00001898 & 0.0139570^2 \end{bmatrix}. \quad (3.59)$$

We find that (1) productivity in Mexico shows a lower persistence than in the U.S.; (2) the spillover estimates are not statistically different from zero (although the point estimate of the U.S.-to-Mexico spillover is positive and notably larger than that for the Mexico-to-U.S. one); thus, we set them to be zero in the model calibration; (3) the productivity process is notably more volatile in Mexico than in the U.S.; (4) the correlation between the productivity innovations in the U.S. and Mexico (0.27) is only slightly higher than the one provided by Backus, Kehoe, and Kydland (1992) for the U.S. and Europe (0.26), but lower than the one they find for the U.S. and Canada (0.43).

In Table 3 (Panel A) we report the empirical correlations of border apprehensions (which we use as a proxy for the entry of immigrants) and remittances with (1) the ratio of real GDP in the U.S. and Mexico adjusted for the real exchange rate, (2) real GDP in the U.S., and (3) real GDP in Mexico. In the data, immigrant entry and remittances are pro-cyclical with the U.S.-Mexico GDP ratio, pro-cyclical with the U.S. GDP, and counter-cyclical with

(TFP) processes are stationarity (See Rabanal et al., 2008). For model comparison we follow these guidelines.
²³For Mexico, we use the Solow residual data in Aguiar and Gopinath (2007).

Mexico's GDP.

Table 3. Correlations of labor migration flows and remittances²⁴

(A) Empirical moments			
	$\frac{GDP_{US}}{Q * GDP_{Mex}}$	GDP_{US}	GDP_{Mex}
Immigrant entry	0.28	0.28	-0.16
Remittances	0.50	0.49	-0.35
(B) Baseline model with bonds			
	$\frac{GDP_h}{Q * GDP_f}$	GDP_h	GDP_f
Immigrant entry	0.98	0.22	-0.87
Remittances	0.39	0.88	-0.05
(C) Alternative model with bonds			
	$\frac{GDP_h}{Q * GDP_f}$	GDP_h	GDP_f
Immigrant entry	0.98	0.03	-0.96
Remittances	0.54	0.87	-0.19

Both the baseline and alternative models replicate qualitatively the cyclicity of migration flows and remittances observable from the data (Table 3, Panels B and C). The models generate labor migration flows (L_e) that are pro-cyclical with the GDP ratio between the two economies, pro-cyclical with the GDP of the destination economy (Home), and counter-cyclical with the GDP of the economy where the immigrant labor originates

²⁴We report the empirical correlations of series in natural logs and HP-filtered. For each economy, the theoretical GDP is measured in units of the consumption basket, $GDP_h = p_h y_h$ and $GDP_f = p_f y_f$. Theoretical remittances are measured in units of the home consumption basket.

(Foreign). The models also replicate the cyclical behavior of the "altruistic" remittance flows from the U.S. to Mexico. In both models, the remittance flows are procyclical with the GDP ratio between Home and Foreign, pro-cyclical with the GDP of the economy where the immigrant labor earns its income (Home), and counter-cyclical with the GDP of the economy that receives remittances (Foreign).²⁵

Table 4 Theoretical and Empirical Moments of Macroeconomic Variables

	Data	No migration	Labor migration	
Correlations:	(U.S.-Mexico)	(BKK94)	Baseline	Alternative
GDP_h, GDP_f	0.16	0.28	0.27	0.26
C, C^*	-0.04	0.43	0.47	0.61

International real business cycle (IRBC) models have difficulty in accounting for a set of empirical patterns visible in cross-country data (Heathcote and Perri, 2002), and our model of immigration and remittances is no exception. In particular, the empirical cross-country correlations for consumption are lower than for output, whereas the IRBC framework generates consumption correlations that are notably higher than the corresponding output correlations (Table 4). In fact, adding labor migration flows and remittances as an extra insurance mechanism enhances the correlation of consumption in the baseline and alternative models with labor migration relative to the model with no labor mobility. This result

²⁵Our measure of remittances "inherits" one of the risk-sharing anomalies of the IRBC framework. Namely, following a productivity increase in Home, the real exchange rate depreciates. Due to the increase in the foreign price index, the immigrant labor income and remittances decrease when measured in units of the foreign consumption basket, although they increase when measured in units of the home basket. As a result, the correlation of remittances measured in units of the home basket (as in Table 5.1) with the foreign GDP is negative (as in the data), whereas the correlation of remittances measured in units of the foreign basket with foreign GDP is positive (contrary to the data).

highlights the insurance role of labor migration and remittances in generating cross-country consumption smoothing.

3.6 Welfare Implications

3.6.1 Tightening the Border

In this section we analyze the welfare effects of a sudden and permanent increase in the sunk immigration cost in the baseline setup (from $f_e = 4$ to $f_e = 5$) that could be related to an increase in border enforcement. The transition paths to a new steady state in Figure 8 show that the declining availability of immigrant labor makes capital less productive and therefore dampens investment, which leads to a decline in the capital stock. Due to the higher entry barriers, firms initially substitute the immigrant for native labor. Despite the lack of increase in native wages, the inter-temporal optimization determines native households to commit more hours in the present, when wages and the return on capital (interest rate) are significantly higher, than in the future. However, as the rate of capital depletion decreases, the incentive for inter-temporal substitution weakens and labor supply increases again, however without exceeding the original steady state.

While the impulse response analysis previously done illustrated the workings of the model, the quantitative welfare analysis needs to take into account that permanent changes in border enforcement have not only cyclical but also permanent effects on the balanced-growth path. We solve the model using a second-order approximation to the policy function around the steady state and consider both temporary stochastic, and permanent determinis-

tic shocks which are perfectly anticipated by economic agents.²⁶ We study the welfare effect of the permanent increase in the sunk cost over a wide range of values for the elasticity of substitution between immigrant and native labor in the baseline model, i.e. $\theta \in [0.5, 2.5]$.

We define welfare (V_t) as the present discounted value of the stream of expected utility. Thus, we compare the welfare of home households in the initial steady-state (V_0) with their welfare as of the period t' when the increase in the sunk cost of immigration takes place. The welfare level as of the period t' takes into account the discounted stream of utilities that the representative household achieves at all periods during the transition path to the new steady state after the permanent increase in the sunk cost of emigration:

$$V_{t'} = E_{t'} \sum_{v=t'}^{\infty} \beta^v U(\bar{C}_v, \bar{L}_v). \quad (3.60)$$

Next we define the constants \bar{C}_0 and \bar{C}_1 to denote the permanent streams of aggregate consumption that would generate the welfare values V_0 and $V_{t'}$: $V_0 = \frac{1}{1-\beta} \ln(\bar{C}_0)$, $V_{t'} = \frac{1}{1-\beta} \ln(\bar{C}_1)$, and compute the consumption-equivalent welfare gain ($\lambda > 0$) or loss ($\lambda < 0$) that corresponds to the permanent increase of the barriers to immigration: $\lambda = \left(\frac{\bar{C}_1}{\bar{C}_0} - 1\right) \times 100$. The results in Figure 9 show that the home economy experiences a consumption-equivalent welfare loss for the entire range of values $\theta \in [0.5, 2.5]$ of the elasticity of substitution between immigrant and native labor. In particular, the loss increases with the degree of complementarity between capital and immigrant labor.

²⁶We add the future values of the deterministic balanced growth path to the list of state variables (see Juillard, 2006, for details).

3.6.2 Alternative Model: Gradual Increase in the Share of Native Skilled

This section explores the impact of immigration barriers on welfare in the presence of a gradual and permanent increase in the share of skilled native labor in Home. In the alternative model with two types of native labor (skilled and unskilled), we introduce a deterministic growth path in the share of skilled native labor in the total population, allowing it to increase from 0.90 to 0.97 over 20 years. In our model parameterization this number accounts for the share of natives without a high school diploma.

We assume that households take into account with perfect certainty the expected growth path of the share of skilled labor when solving their inter-temporal optimization problem, and compute the consumption-equivalent welfare gain (or loss) associated with the increasing share of skilled labor relative to the initial steady state. To this end, we compare the home welfare in the initial steady state:

$$V_0 = \frac{1}{1 - \beta} \{ \phi s U(\bar{c}_s, \bar{l}_s) + (1 - \phi)(1 - s) U(\bar{c}_u, \bar{l}_u) \} \quad (3.61)$$

with home welfare as of period t' when households learn about the growth path of the share of skilled labor:

$$V_{t'} = E_{t'} \sum_{v=t'}^{\infty} \beta^v \{ \phi s_v U(c_{s,v}, l_{s,v}) + (1 - \phi)(1 - s_v) U(c_{u,v}, l_{u,v}) \}. \quad (3.62)$$

The results in Figure 10 show that an economy is likely to experience a welfare loss from maintaining immigration barriers for the unskilled when its share of skilled native labor increases over time. The welfare loss increases with the magnitude of barriers to

immigration and with the degree of complementarity between capital and immigrant labor. Although the immigrant and native unskilled labor are perfect substitutes, the welfare loss suffered by the home unskilled households is offset by the larger accumulation of capital which enhances the productivity of the home skilled labor in the presence of immigration. In particular, for very low values of θ (for which it is particularly difficult to substitute away from unskilled labor), we obtain the paradoxical result that the economy becomes worse off as it limits the inflow of unskilled immigrants, despite the accumulation of human capital.

Using the alternative model with two types of native labor (skilled and unskilled), we repeat the welfare analysis with the share of skilled native labor increasing deterministically from a lower initial level (i.e. from 0.60 to 0.67 over 20 years). As shown in Figure 11, in contrast to the previous exercise, we find that the welfare gain increases with border enforcement. When a larger fraction of the native labor becomes exposed to competition from the immigrant labor, the welfare loss of the home unskilled offsets the welfare gains of the home skilled labor that benefits from the greater accumulation of capital. This leads to an overall welfare loss for the home economy.

To sum up, the results indicate that stricter border enforcement reduces welfare for economies in which unskilled labor is becoming relatively scarce, particularly when it is hard to substitute unskilled for skilled labor. In contrast, economies with relatively abundant amounts of unskilled labor experience welfare losses from lowering the barriers to immigration, particularly when it is easy to substitute unskilled for skilled labor.

3.7 Conclusion

This paper attempts to bridge the gap between modern international macroeconomics and immigration theory. In contrast to the former, we allow for labor mobility across countries; in contrast to the latter, we consider the business cycle dynamics and account for the transmission of aggregate stochastic shocks across countries in the presence of labor migration. In this context, we study the role of labor migration in explaining the behavior of remittances across the economies involved. Thus, we consider the insurance role of remittances as a substitute for contingent claims in smoothing the consumption of households in the country of origin. We also examine the effect of immigration policy on the volatility of labor migration and remittance flows.

In the baseline model, we introduce labor migration flows within a parsimonious standard two-country model of international real business cycles. The incentive to emigrate depends on the difference between the expected future earnings at the destination and in the country of origin, as well as on the perceived sunk costs of labor migration which reflects the immigration policy at the destination. In an alternative specification, we extend the baseline model to allow for skill heterogeneity among the native labor in the destination economy in the presence of capital-skill complementarity.

The impulse responses and theoretical moments show that both model specifications match qualitatively the cyclical dynamics of labor migration and remittances that we document using data for the U.S. and Mexico. Restricting immigration dampens the adjustment in the stock of established immigrant labor during both expansions and recessions in the destination economy, and thus enhances the volatility of immigrant labor income and remit-

tances. The welfare analysis also shows that the overall gain from unskilled immigration for the destination economy increases with the degree of complementarity between the skilled and unskilled labor, as well as with the share of the skilled in total native labor.

International real business cycle models have difficulty in reconciling their risk sharing implications with the empirical evidence. Recent contributions properly address these concerns while extending the standard setup (see for example, Boz et al., 2008; Corsetti et al., 2008; Rabanal et al., 2008, among others). Accounting for these contributions can improve the match between our model's implications and the data. Finally, although we acknowledge the importance of the cross-country migration of skilled labor, we do not model it in this paper. Future research should explore these issues.

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3.A Appendix

3.A.1 Baseline Model of Labor Migration with Financial Autarky, Steady State

The foreign economy In steady state, $A^* = 1$. With the classic Cobb-Douglas production function $Y_f = (K^*)^{\alpha^*} (L_f^*)^{1-\alpha^*}$, it is straightforward to solve for the steady state in the foreign economy:

$$r^* = \frac{1 - \beta^*}{\beta^*}, \quad (3.63)$$

$$\frac{Y_f}{K^*} = \frac{r^* + \delta^*}{\alpha^*}, \quad (3.64)$$

$$K^* = \left(\frac{Y_f}{K^*} \right)^{\frac{1}{\alpha^*-1}} L_f^*, \quad (3.65)$$

$$Y_f = \left(\frac{Y_f}{K^*} \right) K^* = \left(\frac{r^* + \delta^*}{\alpha^*} \right)^{\frac{\alpha^*}{\alpha^*-1}} L_f^*, \quad (3.66)$$

$$w^* = (1 - \alpha^*) \frac{Y_f}{L_f^*} = (1 - \alpha^*) \left(\frac{r^* + \delta^*}{\alpha^*} \right)^{\frac{\alpha^*}{\alpha^*-1}}, \quad (3.67)$$

$$I^* = \delta^* K^*. \quad (3.68)$$

The home economy For the home economy, we solve the steady state numerically using a system of eight non-linear equations (3.69, 3.70, 3.74-3.79) in eight unknowns (Y_h , K , L_i , Y_{h2} , Y_{f1} , p_h , p_f , Q), as described below.

Equations 1-2: With $A = 1$, output and the marginal product of capital are:

$$Y_h = K^\alpha \left[\gamma^{\frac{1}{\theta}} (L_i)^{\frac{\theta-1}{\theta}} + (1 - \gamma)^{\frac{1}{\theta}} (\zeta L_n)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1} (1-\alpha)}, \quad (3.69)$$

$$\frac{\partial Y_h}{\partial K} = \alpha \frac{Y_h}{K} = r + \delta. \quad (3.70)$$

Equation 3: Using the steady-state expression for the present discounted value of the

future gains from immigration, $f_e Q^{-1} w_i = \frac{\beta^*(1-\delta_l)}{1-\beta^*(1-\delta_l)} d$, we obtain:

$$Q^{-1} w_i = w^* + d, \quad (3.71)$$

$$= w^* + \frac{1 - \beta^*(1 - \delta_l)}{\beta^*(1 - \delta_l)} f_e Q^{-1} w_i. \quad (3.72)$$

Thus, the steady state ratio of the immigrant wage and the wage in in the country of origin expressed in units of the same consumption basket is:

$$\Theta \equiv \frac{w_i}{w^* Q} = \left[1 - \frac{1 - \beta^*(1 - \delta_l)}{\beta^*(1 - \delta_l)} f_e \right]^{-1}, \quad (3.73)$$

where $\Theta = 1$ when $f_e = 0$, i.e. with zero sunk cost of labor migration, the wage ratio is equal to unit.

Next, we insert $w_i = \frac{\partial Y_h}{\partial L_i}$ and $w^* = \frac{\partial Y_f}{\partial L^*}$ into the previous equation to obtain:

$$\underbrace{(1 - \alpha) (Y_h)^{\frac{1-\theta\alpha}{\theta(1-\alpha)}} K^{\frac{\alpha(\theta-1)}{\theta(1-\alpha)}} \left(\frac{\gamma}{L_{i,t}} \right)^{\frac{1}{\theta}}}_{w_i} = \Theta \underbrace{(1 - \alpha^*) \left(\frac{r^* + \delta^*}{\alpha^*} \right)^{\frac{\alpha^*}{\alpha^*-1}}}_{w^*} Q. \quad (3.74)$$

Equation 4: The balanced current account condition implies:

$$p_h Y_{h2} = p_f Q Y_{f1} + L_i w_i - \frac{L_i}{L^*} C^* Q, \quad (3.75)$$

where w_i is given above, and:

$$Y^* = \left[\omega^{*\frac{1}{\mu}} (Y_f - Y_{f1})^{\frac{\mu-1}{\mu}} + (1 - \omega^*)^{\frac{1}{\mu}} (Y_{h1})^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}},$$

$$Y_f = \left(\frac{r^* + \delta^*}{\alpha^*} \right)^{\frac{\alpha^*}{\alpha^*-1}} (L^* - L_i),$$

$$L_e = \frac{\delta_l}{1 - \delta_l} L_i.$$

Equations 5-6: We write the demand ratios for the two intermediate goods in each

economy as:

$$\frac{Y_h - Y_{h2}}{Y_{f1}} = \frac{\omega}{1 - \omega} \left(\frac{p_h}{p_f Q} \right)^{-\mu}, \quad (3.76)$$

$$\frac{Y_f - Y_{f1}}{Y_{h2}} = \frac{\omega^*}{1 - \omega^*} \left(\frac{p_f Q}{p_h} \right)^{-\mu^*}. \quad (3.77)$$

Equations 7-8: The price indexes for the composite good of each country are:

$$1 = \omega (p_h)^{1-\mu} + (1 - \omega)(p_f Q)^{1-\mu}, \quad (3.78)$$

$$1 = \omega^* (p_f)^{1-\mu^*} + (1 - \omega^*) \left(\frac{p_h}{Q} \right)^{1-\mu^*}. \quad (3.79)$$

3.A.2 Alternative Model of Labor Migration with Financial Autarky, Steady State

The presence of skill heterogeneity among native labor (skilled and unskilled) in Home requires several modifications in the calculation of steady state relative to the baseline model. In the system of eight equations in eight unknowns described above, L_n becomes L_s (i.e. native skilled labor). One must also distinguish between individual vs. aggregate labor supply (i.e. l_j vs. L_j) and consumption (i.e. c_j vs. C_j) for the representative skilled and unskilled households (where $j \in \{s, u\}$). Thus, equations 3.69, 3.70, 3.74 and 3.75 are replaced by:

$$(Y_h)^{\frac{\theta-1}{\theta}} = \gamma^{\frac{1}{\theta}} (L_i + L_u)^{\frac{\theta-1}{\theta}} + (1 - \gamma)^{\frac{1}{\theta}} \left[\lambda^{\frac{1}{\eta}} K^{\frac{\eta-1}{\eta}} + (1 - \lambda)^{\frac{1}{\eta}} (\zeta L_s)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1} \frac{\theta-1}{\theta}}, \quad (3.80)$$

$$r + \delta = \xi_1 (Y_h)^{\frac{1}{\theta}} \left[\lambda^{\frac{1}{\eta}} K^{\frac{\eta-1}{\eta}} + (1 - \lambda)^{\frac{1}{\eta}} (\zeta L_s)^{\frac{\eta-1}{\eta}} \right]^{\frac{\theta-\eta}{(\eta-1)\theta}} K^{-\frac{1}{\eta}}, \quad (3.81)$$

$$\underbrace{\left(\gamma \frac{Y_h}{L_i + L_u} \right)^{\frac{1}{\theta}}}_{w_i} = \underbrace{\Theta (1 - \alpha^*) \left(\frac{r^* + \delta^*}{\alpha^*} \right)^{\frac{\alpha^*}{\alpha^* - 1}}}_{w^*} Q, \quad (3.82)$$

$$p_h Y_{h2} = p_f Q Y_{f1} + L_i \underbrace{\left(\gamma \frac{Y_h}{L_i + L_u} \right)^{\frac{1}{\theta}}}_{w_i} - \frac{L_i}{L^*} C^* Q. \quad (3.83)$$

3.A.3 Labor Migration with International Trade in Bonds, Steady State

The presence of quadratic costs of adjustment for bond holdings allows us to pin down their steady-state levels. From $1 + \pi B_h = \beta(1 + r^b)$, $1 + \pi B_h^* = \beta^*(1 + r^b)$ and $B_h + B_h^* = 0$, it follows that:

$$r^b = \frac{2}{\beta + \beta^*} - 1, \quad (3.84)$$

$$B_h = -B_h^* = \frac{\beta(1 + r^b) - 1}{\pi}. \quad (3.85)$$

Similarly, using that $1 + \pi B_f = \beta(1 + r^{b*})$, $1 + \pi B_f^* = \beta^*(1 + r^{b*})$ and $B_f + B_f^* = 0$, it follows that:

$$r^{b*} = \frac{2}{\beta + \beta^*} - 1 = r^b, \quad (3.86)$$

$$B_f = -B_f^* = \frac{\beta(1 + r^{b*}) - 1}{\pi}. \quad (3.87)$$

Finally, the balanced current account condition (3.75) is replaced by the expression for the balance of international payments (3.44) in steady state:

$$p_h Y_{h2,t} - p_f Y_{f1} Q - \underbrace{\left(w_i L_i - \frac{L_i}{L^*} C^* Q \right)}_{\text{Remittances}} + r^b B_h + r^{b*} Q B_f = 0. \quad (3.88)$$

The steady state solutions for the remaining variables are as in Appendix A.1 and A.2.

3.A.4 Benchmark Model without Labor Migration (BKK94)

In the model without labor migration, each country specializes in the production of a single good, labeled $Y_{h,t}$ for home and $Y_{f,t}$ for foreign, as in Backus, Kehoe, Kydland (1994). We use log-CRRA preferences and abstract from government purchases and time-to-build in capital formation.

The model with financial autarky The home economy is characterized by 11 equations in 11 variables ($r_t, w_t, C_t, L_t, Y_{h,t}, Y_t, Y_{h2,t}, I_t, K_t, p_{h,t}$):

$$1 = \beta(1 + r_t)E_t \left(\frac{C_t}{C_{t+1}} \right), \quad (3.89)$$

$$\frac{w_t}{C_t} = \chi L_t^\psi, \quad (3.90)$$

$$Y_{h,t} = A_t K_{t-1}^\alpha L_t^{1-\alpha}, \quad (3.91)$$

$$Y_{h,t} = Y_{h1,t} + Y_{h2,t}, \quad (3.92)$$

$$(Y_t)^{\frac{\mu-1}{\mu}} = \omega^{\frac{1}{\mu}} (Y_{h,t} - Y_{h2,t})^{\frac{\mu-1}{\mu}} + (1 - \omega)^{\frac{1}{\mu}} (Y_{f1,t})^{\frac{\mu-1}{\mu}}, \quad (3.93)$$

$$Y_t = C_t + I_t, \quad (3.94)$$

$$K_t = I_t + (1 - \delta) K_{t-1}, \quad (3.95)$$

$$Y_{h1,t} = \omega (p_{h,t})^{-\mu} Y_t, \quad (3.96)$$

$$Y_{f1,t} = (1 - \omega) (p_{f,t} Q_t)^{-\mu} Y_t, \quad (3.97)$$

$$r_t = \alpha \frac{Y_{h,t+1}}{K_t} - \delta \quad (3.98)$$

$$w_t = (1 - \alpha) \frac{Y_{h,t}}{L_t} \quad (3.99)$$

All equations for the foreign economy are similar. Note that the price of the home intermediate good expressed in units of the foreign consumption basket is $Q_t^{-1} p_{h,t}$; therefore, the demand functions for the home and foreign-specific good in the foreign economy are: $Y_{f2,t} = \omega^* (p_{f,t})^{-\mu} Y_t^*$ and $Y_{h2,t} = (1 - \omega^*) (Q_t^{-1} p_{h,t})^{-\mu} Y_t^*$, respectively.

Technology follows the process:

$$\log A_t = \rho \log A_{t-1} + e_t,$$

$$\log A_t^* = \rho \log A_{t-1}^* + e_t^*$$

The real exchange rate Q_t is pinned down by the trade balance, measured in units of the home composite good:

$$NX_t = \underbrace{Y_{h2,t} p_{h,t}}_{\text{exports}} - \underbrace{Y_{f1,t} p_{f,t} Q_t}_{\text{imports}}. \quad (3.100)$$

Under financial autarky and without remittances, $NX_t = 0$.

Financial integration, trade in risk-free bonds International trade in risk-free bonds (with quadratic cost of adjustment of bond holdings) adds 6 extra variables (i.e. the rates of return of the home and foreign bonds, r_t^b and r_t^{b*} ; holdings of the home and foreign bonds by home households, $B_{h,t}$ and $B_{f,t}$; holdings of the home and foreign bonds by foreign households, $B_{h,t}^*$ and $B_{f,t}^*$) and 6 new equations to the model with financial autarky:

$$1 + \pi B_{h,t+1} = \beta(1 + r_{t+1}^b)E_t \left[\frac{C_t}{C_{t+1}} \right], \quad (3.101)$$

$$1 + \pi B_{f,t+1} = \beta(1 + r_{t+1}^{b*})E_t \left[\frac{Q_{t+1}}{Q_t} \frac{C_t}{C_{t+1}} \right], \quad (3.102)$$

$$1 + \pi B_{h,t+1}^* = \beta^*(1 + r_{t+1}^b)E_t \left[\frac{Q_t}{Q_{t+1}} \frac{C_t^*}{C_{t+1}^*} \right], \quad (3.103)$$

$$1 + \pi B_{f,t+1}^* = \beta^*(1 + r_{t+1}^{b*})E_t \left[\frac{C_t^*}{C_{t+1}^*} \right], \quad (3.104)$$

$$B_{h,t+1} + B_{h,t+1}^* = 0, \quad (3.105)$$

$$B_{f,t+1} + B_{f,t+1}^* = 0. \quad (3.106)$$

The expression for the balance of international payments replaces the balanced trade condition from the model with financial autarky:

$$p_{h,t}Y_{h2,t} - p_{f,t}Q_tY_{f1,t} + r_t^bB_{h,t} + r_t^{b*}Q_tB_{f,t} = 0. \quad (3.107)$$

3.A.5 Benchmark Model without Labor Migration (BKK94), Steady State

In steady state, $A = A^* = 1$. In each country,

$$r = \frac{1 - \beta}{\beta}, r^* = \frac{1 - \beta^*}{\beta^*}, \quad (3.108)$$

$$\alpha \frac{Y_h}{K} - \delta = r \rightarrow \frac{Y_h}{K} = \frac{r + \delta}{\alpha}, \frac{Y_f}{K^*} = \frac{r^* + \delta^*}{\alpha^*}, \quad (3.109)$$

$$Y_h = K^\alpha L^{1-\alpha} \rightarrow K = \left(\frac{Y_h}{L} \right)^{\frac{1}{\alpha-1}}, K^* = \left(\frac{Y_f}{L^*} \right)^{\frac{1}{\alpha^*-1}}, \quad (3.110)$$

$$Y_h = \left(\frac{Y_h}{K} \right) K = \left(\frac{r + \delta}{\alpha} \right)^{\frac{\alpha}{\alpha-1}} L, Y_f = \left(\frac{r^* + \delta^*}{\alpha^*} \right)^{\frac{\alpha^*}{\alpha^*-1}} L^*, \quad (3.111)$$

$$I = \delta K, I^* = \delta^* K^*. \quad (3.112)$$

The symmetric case The solution with symmetric calibration parameters for the two economies is described by:

$$p_h = p_f = Q = 1. \quad (3.113)$$

$$Y_{h1} = Y_{f2} = \omega Y_h. \quad (3.114)$$

$$Y_{h2} = Y_{f1} = (1 - \omega) Y_h, \quad (3.115)$$

where $(1 - \omega)$ represents the share imports in GDP. Using that $Y_{h1} = \omega Y_h$ and $Y_{h2} = (1 - \omega) Y_h$,

$$Y = \left[\omega^{\frac{1}{\mu}} (Y_{h1})^{\frac{\mu-1}{\mu}} + (1 - \omega)^{\frac{1}{\mu}} (Y_{f1})^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}} = Y_h, \quad (3.116)$$

$$C = Y - I. \quad (3.117)$$

Asymmetric steady state This section describes the steady-state solution for cross-country asymmetries of the type $\alpha \neq \alpha^*, \beta \neq \beta^*, \mu \neq \mu^*$ and $\omega \neq \omega^*$. The equations (3.108)-(3.112) still hold. We obtain the steady-state solutions numerically using a system

of 5 equations in 5 unknowns $(Y_{h1}, Y_{f2}, p_h, p_f, Q)$:

$$\frac{Y_{h1}}{Y_f - Y_{f2}} = \frac{\omega}{1 - \omega} \left(\frac{p_h}{p_f Q} \right)^{-\mu}, \quad (3.118)$$

$$\frac{Y_{f2}}{Y_h - Y_{h2}} = \frac{\omega^*}{1 - \omega^*} \left(\frac{p_f Q}{p_h} \right)^{-\mu^*}, \quad (3.119)$$

$$1 = \omega (p_h)^{1-\mu} + (1 - \omega)(p_f Q)^{1-\mu}, \quad (3.120)$$

$$1 = \omega^* (p_f)^{1-\mu^*} + (1 - \omega^*) \left(\frac{p_h}{Q} \right)^{1-\mu^*} \quad (3.121)$$

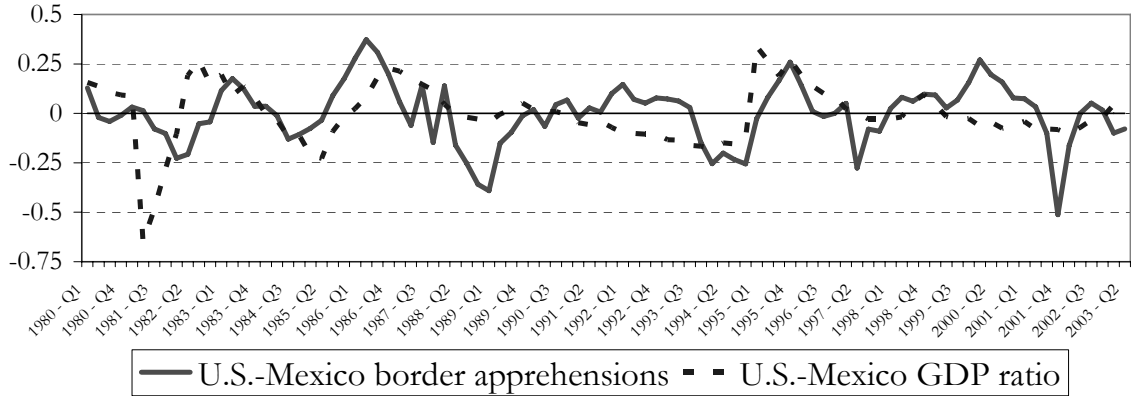
In financial autarky, the balanced trade condition is:

$$Y_{h2} p_h - Y_{f1} p_f Q = 0. \quad (3.122)$$

With financial integration, balanced trade is replaced by the expression for the balance of international payments:

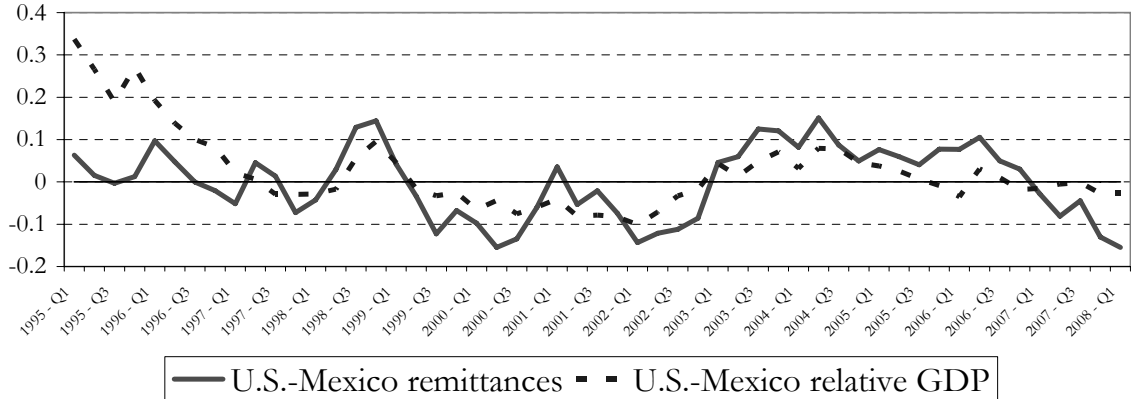
$$p_h Y_{h2} - p_f Q Y_{f1} + r^b B_h + r^{b^*} Q B_f = 0. \quad (3.123)$$

Figure 1. U.S.-Mexico border apprehensions and the U.S.-Mexico GDP ratio



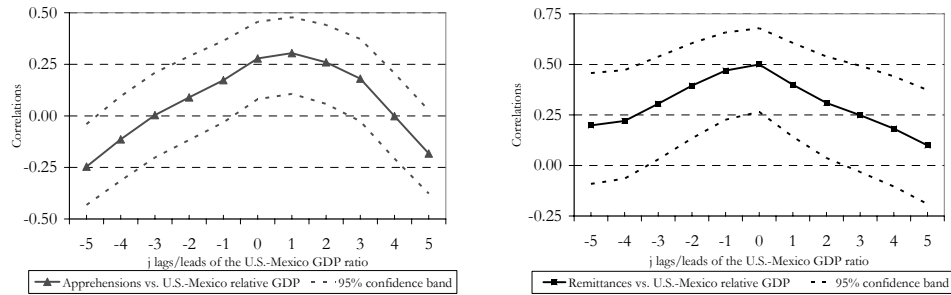
Source: Hanson (2007), *Haver Statistics*, and International Financial Statistics (2008).
 Note: We have seasonally-adjusted the series for border apprehensions using the X-12 ARIMA method of the U.S. Census Bureau. The resulting seasonally-adjusted series were logged and HP(1600) filtered. The U.S.-Mexico GDP ratio is computed as the ratio between (1) the U.S. real GDP and (2) the real Mexican GDP multiplied by the bilateral real exchange rate.

Figure 2. U.S.-Mexico remittances and the U.S.-Mexico GDP ratio



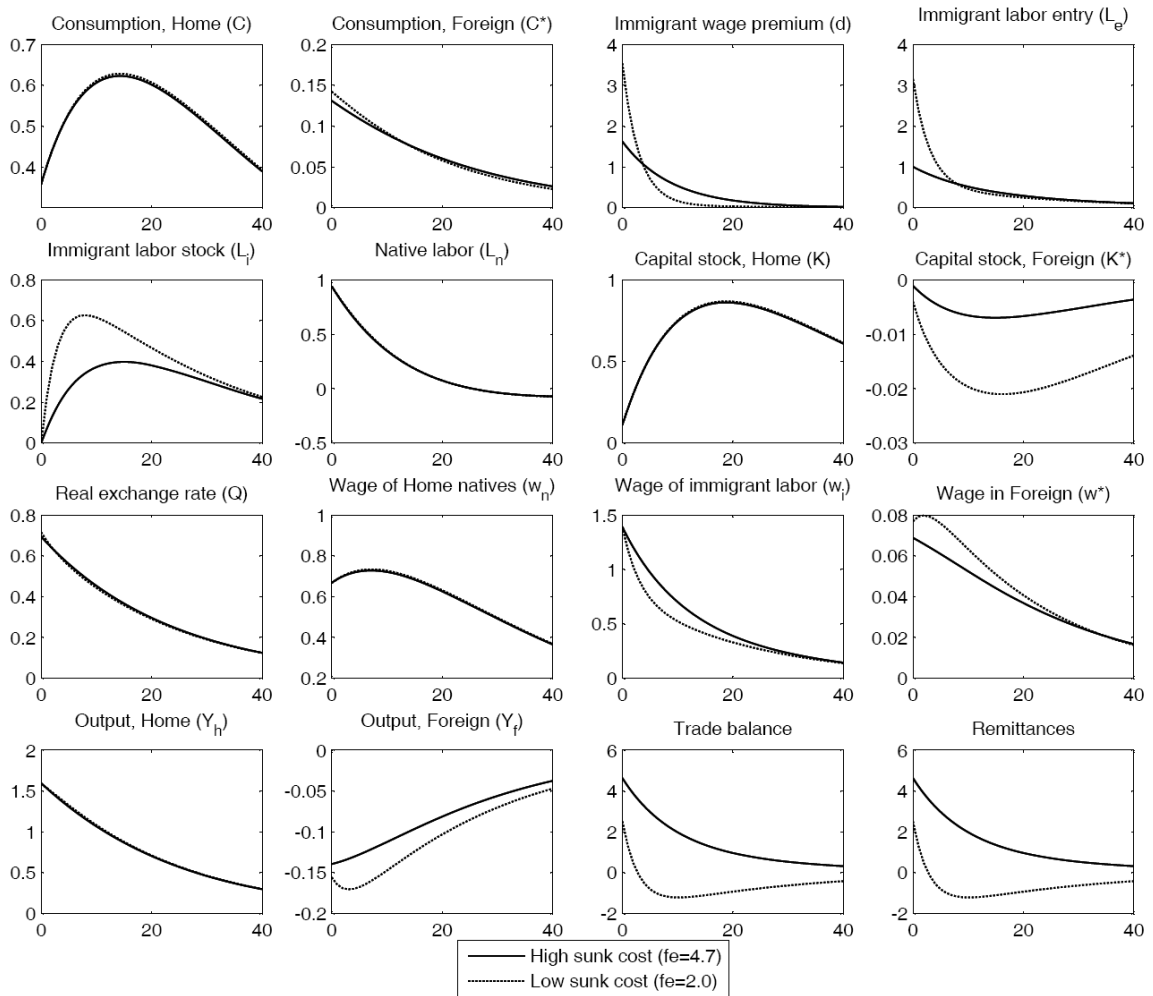
Source: *Haver Statistics* and Banco de México. Remittances are expressed in Mexican pesos at constant prices. Series were seasonally adjusted and detrended with the methods described in Figure 1.

Figure 3. Correlations of U.S.-Mexico border apprehensions (left) and U.S.-Mexico remittances (right) with the j lags and leads of the U.S.-Mexico GDP ratio



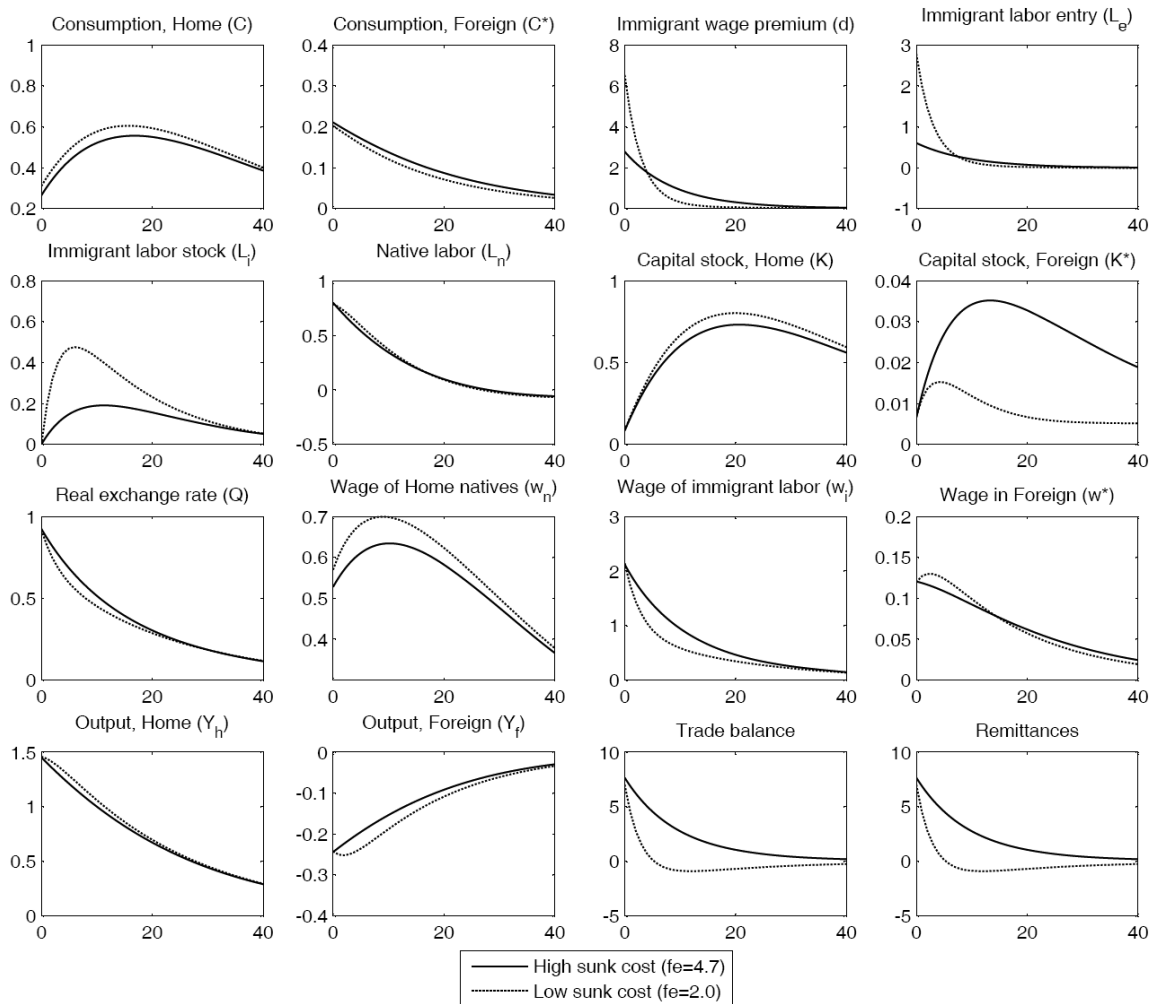
Note: correlations are computed based on the data in Figures 1 and 2, respectively.

Figure 4. Baseline model with financial autarky



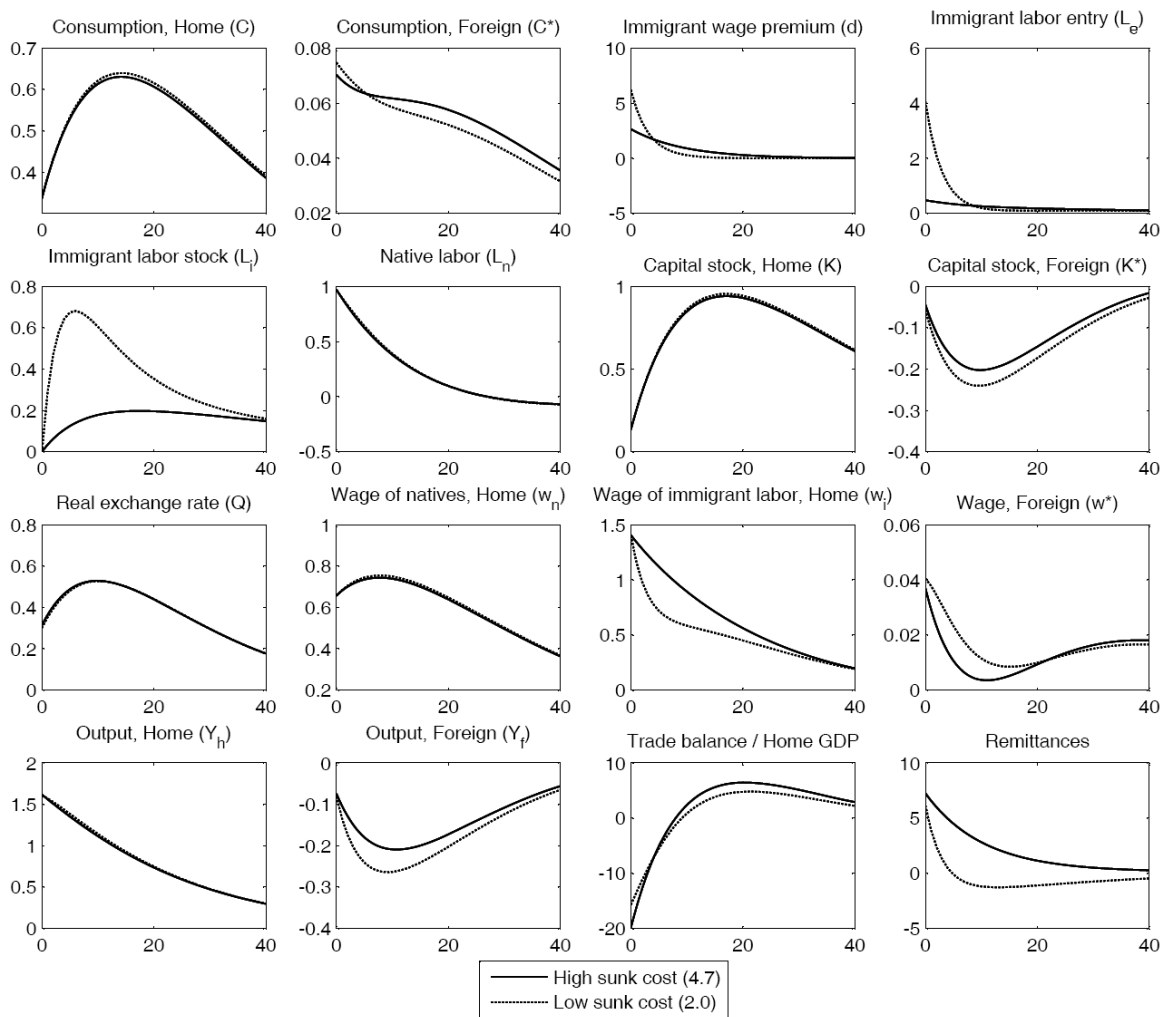
Each panel shows the response (percent deviations from steady state) to a transitory 1 percent increase in home productivity, for the cases with high sunk cost (solid line) and low sunk cost (dashed line).

Figure 5. Baseline model with financial autarky, high complementarity between native and immigrant labor



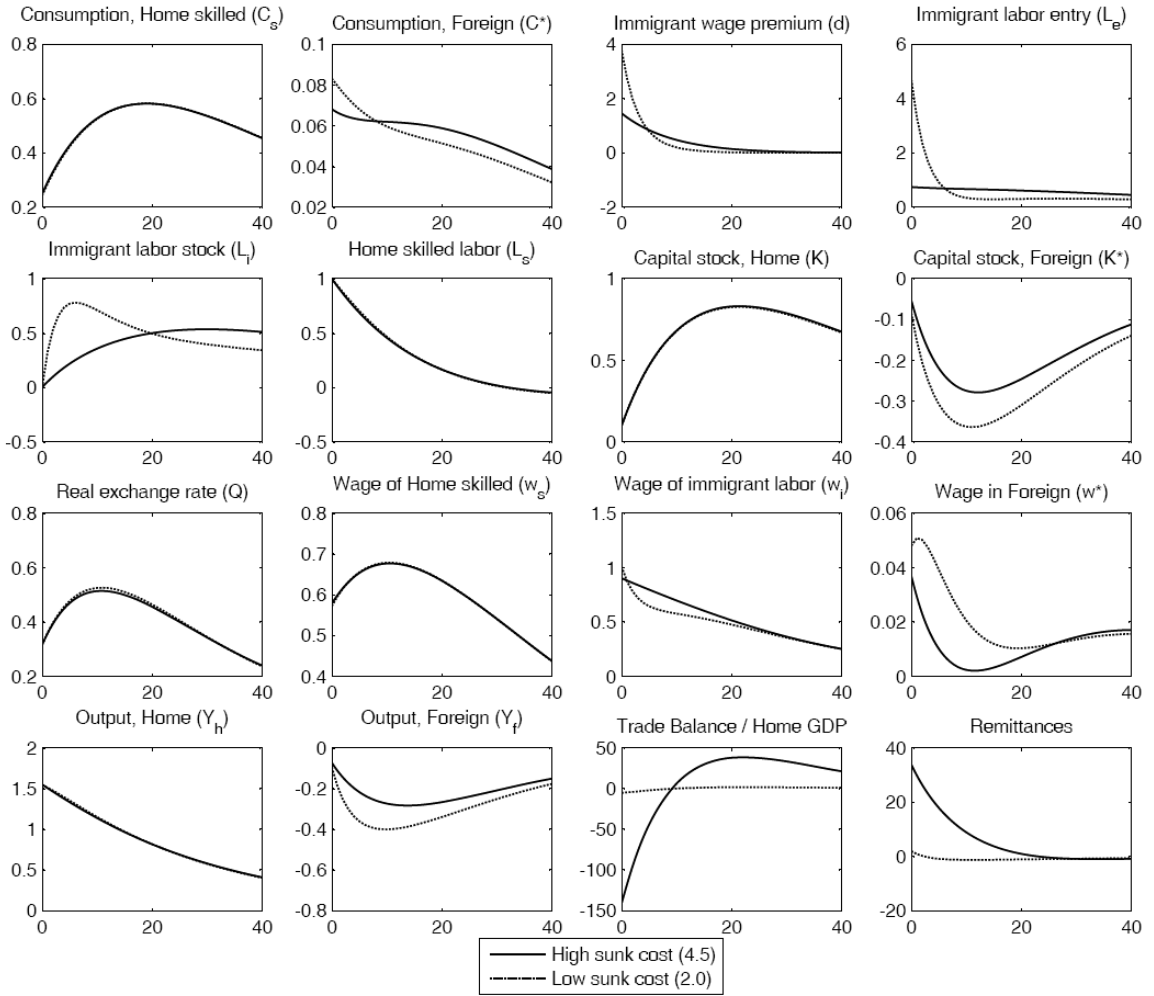
Each panel shows the response (percent deviations from steady state) to a transitory 1 percent increase in home productivity, under high complementarity ($\theta = 0.5$) between the native and immigrant labor, for the cases with high sunk cost (solid line) and low sunk cost (dashed line).

Figure 6. Baseline model with financial integration



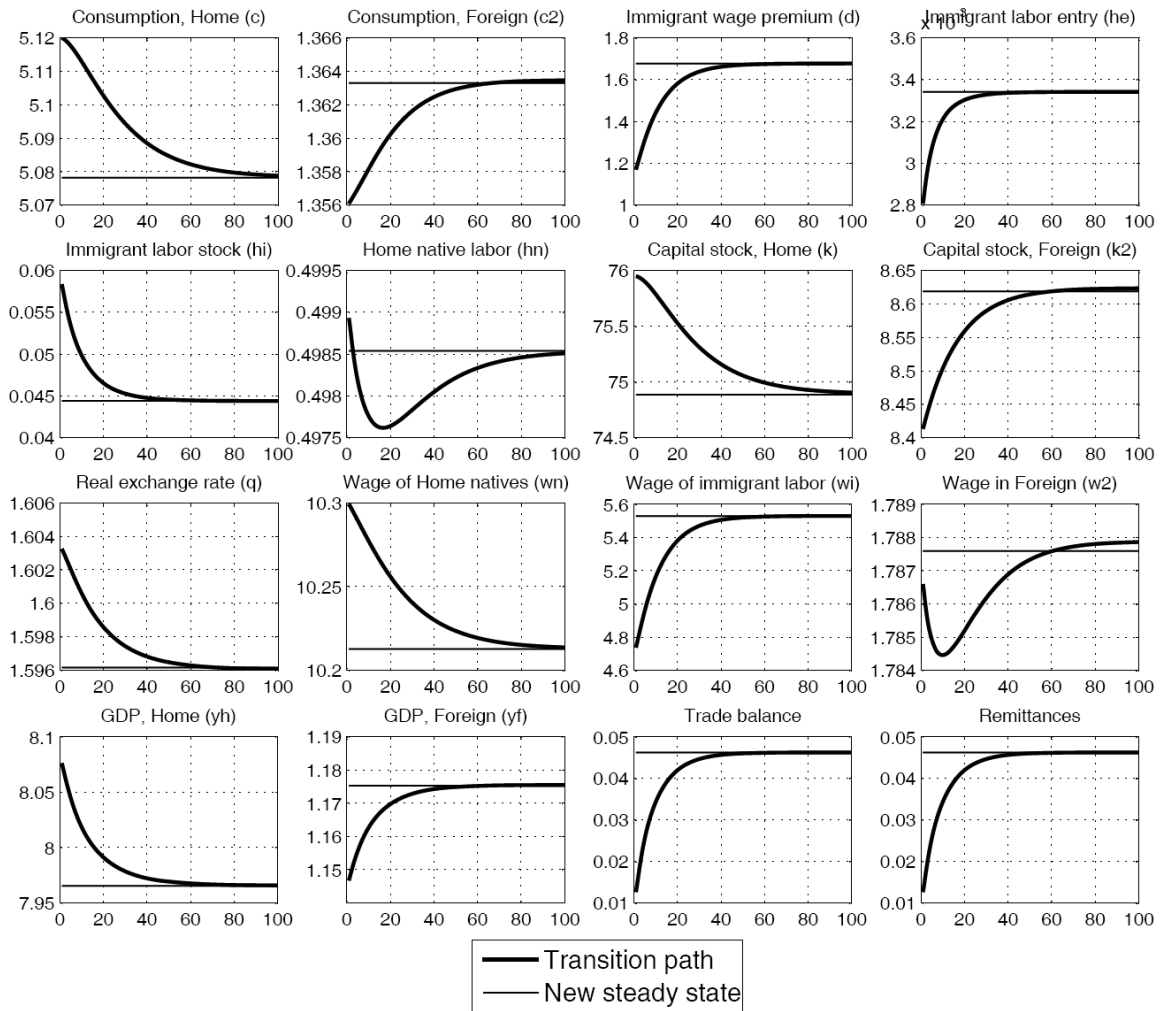
Each panel shows the response (percent deviations from steady state) to a transitory 1 percent increase in home productivity, for the cases with high sunk cost (solid line) and low sunk cost (dashed line). The model allows for international trade in risk-free bonds (with adjustment cost parameter $\pi = 0.0025$).

Figure 7. Alternative model with financial integration



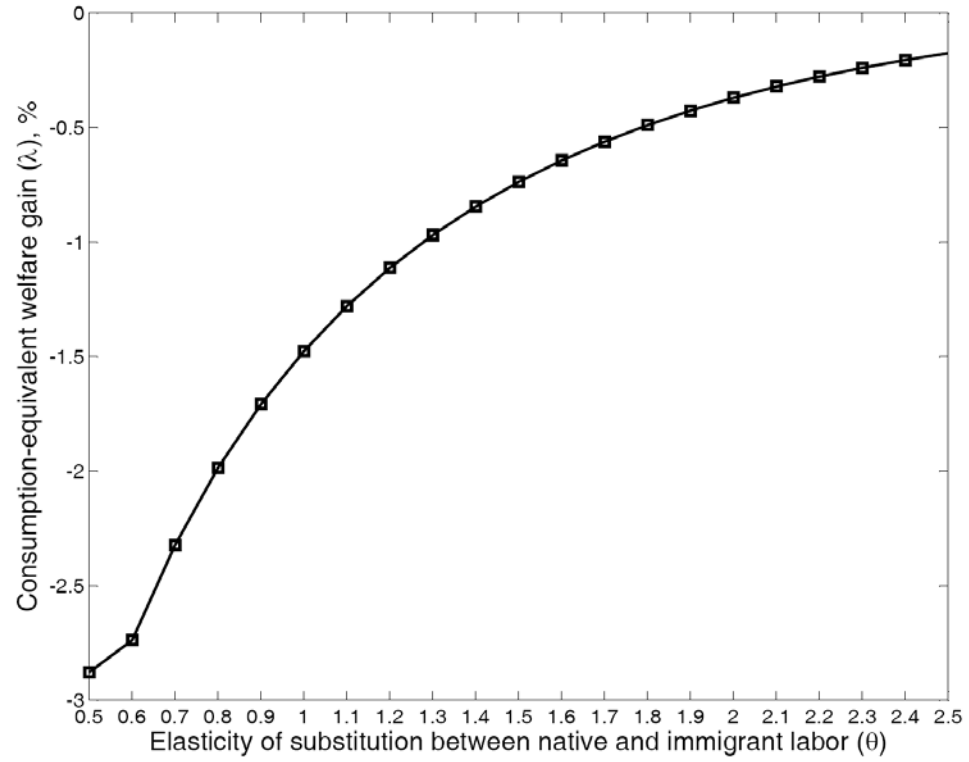
Each panel shows the response (percent deviations from steady state) to a transitory 1 percent increase in home productivity in the alternative model (i.e. with skill heterogeneity among the native labor and capital-skill complementarity), for the cases with high sunk cost (solid line) and low sunk cost (dashed line). The model allows for international trade in risk-free bonds (with adjustment cost parameter $\pi = 0.0025$).

Figure 8. Baseline model with financial autarky: permanent increase in border enforcement



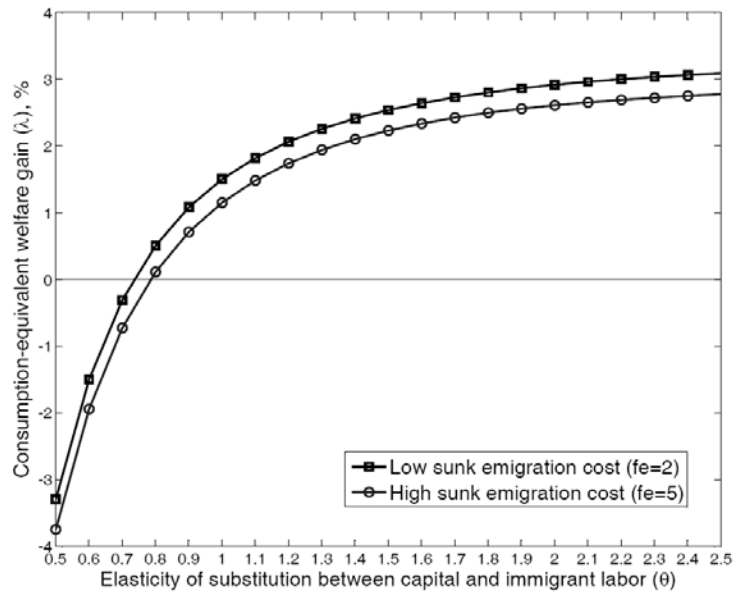
Each panel shows the transition path of the model's variables with a permanent increase in the sunk emigration cost (sudden increase from $f_e=4$ to $f_e=5$).

Figure 9. Welfare analysis, baseline model with financial autarky



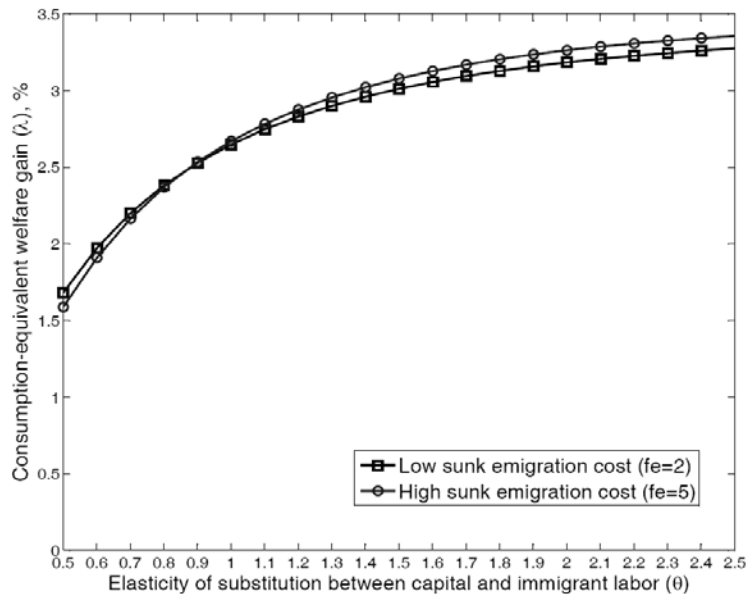
Consumption-equivalent welfare gain/loss with a permanent increase in the sunk emigration cost (sudden increase from $f_e=4$ to $f_e=5$).

Figure 10. Welfare analysis, alternative model with financial autarky: implications of a rising share of skilled labor (1)



Consumption-equivalent welfare gain/loss from a rising share of native skilled labor (from 0.9 to 0.97 over 20 years), in the presence of the sunk emigration cost.

Figure 11. Welfare analysis, alternative model with financial autarky: implications of a rising share of skilled labor (2)



Consumption-equivalent welfare gain/loss from a rising share of native skilled labor (from 0.6 to 0.67 over 20 years), in the presence of the sunk emigration cost.