Volatility Due to Offshoring: Theory and Evidence

Abstract:

This paper develops a theoretical model to study the second moment properties of global offshoring. It offers an explanation for the stylized fact that offshoring industries in Mexico experience fluctuations in employment that are twice as volatile as the corresponding industries in the U.S. The model features an extensive margin of offshoring that responds endogenously to shocks in demand, and transmits those shocks across borders.

JEL classification: F4, F1

I. Introduction

International trade is being transformed by offshoring, the arrangement whereby firms contract to carry out particular stages of production abroad. This especially is true for the U.S. and Mexico. Offshoring accounts for nearly half of Mexico's exports, with Mexican employment in export assembly plants engaged in offshoring growing ten-fold from 0.12 million in 1980 to 1.2 million in 2006. While Mexican officials hail the export assembly plants for their contribution to economic growth, some complain that the sector is fickle and subject to excessive volatility.[1] The assembly plants, known as *maquiladoras*, are seen as a channel by which the U.S. exports to Mexico a portion of its employment fluctuations over the business cycle.

While a growing number of papers model the effects of offshoring on the wage structure, the environment, and other outcomes, ours is among the first to examine the second-moment properties of offshoring, which are at the heart of concerns expressed by policy makers. Bergin, Feenstra, and Hanson (2009) document that maquiladora industries in Mexico associated with U.S. offshoring have fluctuations in employment that are twice as volatile as the corresponding industries in the U.S. This finding is based on data covering Mexico's four largest offshoring industries, apparel, transportation equipment, computers and electronics, and electrical machinery, which are matched to their U.S. counterparts at the three digit level. Across offshoring industries, the standard deviation of employment in Mexico is 2.2 times higher than in the U.S.[2]

One conjecture might be that high volatility in Mexican offshoring industries simply reflects higher volatility in the Mexican economy overall. However, employment volatility for aggregate manufacturing in Mexico is actually lower than in the U.S. A second conjecture might be that labor-market institutions differ between the countries, such that it is easier to hire and fire employees in

[1] See for example the news account of how the Mexican car industry is highly susceptible to fluctuations in demand for American brand automobiles in Dickerson (2005).
[2] See column (1) of table 4 for the values reported in Bergin, Feenstra and Hanson (2009), which are standard deviations computed from monthly data that are seasonally adjusted and HP-filtered in logs over the range 1996:1-2005:12.

Mexico. Yet, when Botero et al. (2004) rank countries in terms of job security laws restricting the hiring and firing of workers, Mexico ties for the most regulated among the 85 countries in the sample, whereas the U.S. ranks as the fifth least regulated economy, a finding consistent with Mexico having lower aggregate employment volatility.[3]

In this paper, we offer an alternative explanation for differential volatility in countries engaged in offshoring. We develop a model of global production sharing where the offshoring decisions of firms respond to macroeconomic shocks. The model relies on a continuum of products in the offshoring sector, and for each product an endogenous number of varieties. This structure combines the Dornbusch-Fisher-Samuelson (1977) framework with the monopolistic competition model, as also done by Romalis (2004). Production in the offshoring sector requires two activities: a fixed-cost activity that occurs in the high-wage home country, representing headquarter and managerial costs, and a variable-cost activity representing assembly work that can be done at home or offshored to a low-wage foreign country. The offshoring sector is embedded in a two country, general equilibrium macroeconomic model, which also includes a homogeneous traded good in each country.

A key feature of the model is that the point along the product continuum at which firms in the home country begin to offshore the variable-cost activity to the foreign country is endogenously determined as firms compare the unit-labor costs across borders. When the home country has a boom in demand, the fact that home wages tend to be procyclical alters the offshoring decision of some firms.[4] Since home workers become relatively more expensive to hire, firms that previously had not

[3] In Mexico, labor unions are active in maquiladoras and other manufacturing establishments, Collective bargaining agreements in maquiladoras appear to be less restrictive than in the rest of Mexican manufacturing, in that job classifications tend to be wider and firms tend to have greater leeway in establishing pay-for-performance schemes (Fairris, 2003). At the same time, the decline in unionization in Mexican manufacturing, which has been ongoing since the 1980s, is less evident among maquiladoras. The net effect of more flexible collective bargaining agreements but more stable union presence is relatively small differences in labor relations between maquiladoras and other Mexican manufacturing firms.

[4] Huang et al. (2004) survey recent evidence confirming procyclicality of wages in the U.S. in the postwar period, unconditionally as well as conditional on demand shocks.

offshored any production now find it profitable to do so. This shift in the extensive margin acts as a powerful mechanism for the international transmission of shocks, whereby U.S. producers shift unusually high levels of production abroad during a domestic economic boom, and the reverse during a recession. Numerical examples, by way of stochastic simulation under demand and supply shocks, indicate that the mechanism provides a potential explanation for the extra volatility in Mexican offshoring. Even when the shock is a purely domestic one, the simulation shows that it is amplified in its transmission abroad, so that it has a greater impact on the offshoring industries in the low-wage foreign country than on the domestic counterpart industries.

There are two reasons in our model why the shocks to home demand are amplified in their effect abroad. First, the foreign offshoring sector, representing maquiladoras in Mexico, has smaller total employment than in the U.S. Any given shift in employment therefore has an amplified effect on foreign volatility. Second, as just noted, home wages are procyclical with home demand shocks. A home demand shock that raises demand in the offshoring industry will tend to raise employment disproportionately in the foreign country, since offshoring activity is shifted in that direction at the same time that employment is growing due to increased demand. In contrast, the shift in offshoring activities offsets part of the employment increase at home.

To motivate the theoretical approach and help calibrate the model, the paper begins by providing novel empirical evidence on movements in the extensive margin of offshoring trade, the entry and exit of new goods. We collect data on Mexican exports at key U.S. ports of entry associated with offshoring, which record both the value of exports and the number of product classifications exported. We find that at a monthly frequency changes in the extensive margin are a statistically significant channel of adjustment in trade.

The paper most closely related to ours is Burstein, Kuz and Tesar (2008), which studies the real business cycle implications of offshoring. Our paper differs from theirs in its focus on volatility rather than cross-country correlations in macroeconomic variables, and in its focus on the maquiladora sector. We are also distinct in modeling offshoring in a manner consistent with recent developments in trade theory, emphasizing a high degree of substitution between production in Mexican plants and their U.S. counterparts.[5]

The next section presents empirical results on the extensive margin, which serve as motivation for our theory. Section 3 presents the theoretical model, analytical results are in section 4, with simulation results in section 5. Conclusions are given in section 6.

II. Empirical Motivation

The theoretical model developed in the following section will imply that changes in employment by offshoring industries are driven in part by adjustment at the extensive margin. The mechanism we have in mind is one in which aggregate shocks alter Mexican wages relative to U.S. wages, inducing an endogenous shift in the extent of production activities U.S. firms offshore to Mexico. If such a mechanism is operative, we should see entry and exit among the assembly plants in Mexico that produce intermediate goods and services for U.S. industry. There is abundant anecdotal evidence of such plant turnover. During the U.S. economic expansion of the 1990s, the number of maquiladoras in Mexico grew from 1,600 to 3,700. Delphi, a large U.S. manufacturer of auto parts, expanded its operations in Mexico to include six assembly plants. As U.S. economic growth slowed in 2001 and 2002, over 700 Mexican maquiladoras closed shop.[6] Delphi shut down two of its Mexican maquiladoras, leaving the other four in operation.[7] Similar expansion and contraction in

[5] Burstein, Kurz, and Tesar (2008) develop a dynamic model of trade in intermediate inputs whose respective outputs are assumed to be complements in production, whereas we model international production in terms of offshoring of variable cost activities that are highly substitutable. Our formulation draws on the offshoring model in Feenstra and Hanson (1996, 1997). For other work on intermediate inputs and business cycle synchronization see Kose and Yi (2001, 2006) and Ambler, Cardia, and Zimmerman (2002).
[6] See "The Decline of the Maquiladora: The Government Isn't Moving to Rescue a Troubled Industry," *Business Week, April 29, 2002.*
[7] See Victoria Hirshberg, "Delphi to Consolidate Reynosa, Mexico, Operations," *Texas Knight Ridder/Tribune Business News*, July 23, 2004.

Mexican assembly plants is evident among firms that produce TV sets, cell phones, computer printers, and other goods.[8]

More formal evidence of adjustment at the extensive margin comes from examining data on the number of products that Mexico exports to the U.S. We use the Harmonized System (HS) import data for the U.S., at a monthly frequency, and focus on the three largest land border crossings: Laredo, El Paso and San Diego. Table 1 summarizes the average number of HS 10-digit products crossing at each location per month in the four offshoring industries identified above. For example, there are 300 or more types of apparel items being imported at Laredo and San Diego each month, and a smaller number of items in other offshoring industries. We also report the mean number of months that HS products in each industry are exported each year, ranging from 5.8 months for apparel items in El Paso, to 9.0 months for transport equipment in Laredo.

These summary statistics show that there are many 'zeros' in the data, i.e. many instances where an HS product is not exported some month. That fact is also illustrated by Figure 1, which graphs the log number of HS products per month, after deseasonalizing and HP filtering. The standard deviation of these series (reported in Table 1), averaged across industries is 3.6%. Some of the fluctuation in the number of HS products will reflect products that are exported at irregular intervals during the year. But we also expect that some fluctuation is systematic: visually, there appears to be a fall in the number of HS products in 2002, at the time when employment in both Mexico and the U.S. fell substantially. That impression is confirmed by the correlations between the number of HS products and U.S. manufacturing employment reported in Table 1, which are nearly all positive and often exceed 0.25.

Beyond confirming that the range of products exported from Mexico is procyclical with U.S. employment, we wish to determine the degree to which there is a systematic component to its

[8] See Mary Jordan, "Mexican Workers Pay for Success," *Washington Post*, June 20, 2002; Elizabeth Malkin, "A Boom along the Border," *The New York Times*, August 26, 2004; and Diane Lindquist, "Slight Gain in Output Cheers Mexico's Beleaguered Maquiladora Industry," *San Diego Union-Tribune*, March 11, 2004.

fluctuation.[9] We evaluate this relationship along the lines of Eaton, Kortum and Kramarz (2004), using the identity:

$$z_{it} \times \frac{E_{it}}{z_{it}} \equiv \frac{E_{it}}{E_t} \times E_t \,, \qquad (1)$$

where z_{it} denotes the number of HS products exported from Mexico in industry *i*, month *t*, and a particular border crossing, E_{it} is the value of exports for that industry *i* and border crossing in month *t*, and E_t is total exports at that border crossing in month *t*. From this identity we specify two regression equations:

$$\ln z_{it} = \alpha_0 + \alpha_1 \ln \frac{E_{it}}{E_t} + \alpha_2 E_t + \varepsilon_{it} \qquad (2)$$

and

$$\ln \frac{E_{it}}{z_{it}} = \beta_0 + \beta_1 \ln \frac{E_{it}}{E_t} + \beta_2 E_t - \varepsilon_{it} \,. \qquad (3)$$

where (E_{it}/ z_{it}) is the average value of Mexican exports per HS product. By the logic of least squares, $\widehat{\alpha}_0 + \widehat{\beta}_0 = 0$, $\widehat{\alpha}_1 + \widehat{\beta}_1 = 1$, and $\widehat{\alpha}_2 + \widehat{\beta}_2 = 1$. The relative magnitude of the coefficients identifies how aggregate shocks affect the number of products (the extensive margin) and exports per product (the intensive margin).

The results from these regressions are shown in columns (1) and (2) of Table 2. All series have been deseasonalized and HP filtered, and then are pooled across the four offshoring industries, with controls included for industry fixed effects. In column (1), the estimate for α_1 is 0.07, which is statistically significant, and for α_2 is 0.10, which is also significant. The first coefficient shows that the number of HS products in each industry responds to a shift in Mexican exports towards that industry. In that sense, the number of products provides an avenue of adjustment. For an increase in

[9] Alessandria, Kaboshki and Midrigan (2007) argue that large devaluations leads to systematic changes in the range of goods exported, also using the monthly 10-digit HS data for the United States.

overall exports (the second coefficient), the number of HS products in the industry also responds by a modest amount.

A problem with using the number of HS products as a measure of adjustment is that the HS classification is quite arbitrary: the classifications are determined more by the need to distinguish tariffs for various items than by any consideration of the value of exports for each product, which might be very small or very large. To address that problem, we consider instead a measure of the extensive margin of exports used by Hummels and Klenow (2005). Let J_{ikt} denote the set of 10-digit Harmonized System exports from Mexico to the U.S. in industry *i*, at border crossing *k*, and month *t*. The extensive margin of exports is a sales-weighted count of the number of products in the set J_{ikt}, relative to the number in a "common" set J_{ik}, which we define as the products exported *every month* within the year. Then the extensive margin is defined as:[10]

$$EM_{ikt} \equiv \sum_{j \in J_{ikt}} \bar{p}_{ijk} \bar{x}_{ijk} \Big/ \sum_{j \in J_{ik}} \bar{p}_{ijk} \bar{x}_{ijk} \quad , \tag{4}$$

where $\bar{p}_{ijk} \bar{x}_{ijk}$ is the value of exports for product *j* in industry *i*, summed across locations *other than* border crossing *k*, and averaged over months within each year. By measuring the value of exports at border crossing *other than k*, and averaging over time, we avoid endogeneity between total monthly exports at each border crossing and the values appearing in (4).

To determine the systematic component of the fluctuations in the extensive margin, we follow Hummels and Klenow (2005) in defining the intensive margin of exports IM_{ikt} by:

$$EM_{ikt} \times IM_{ikt} = \sum_{j \in J_{ikt}} p_{ijkt} x_{ijkt} \, , \tag{5}$$

[10] From Feenstra (1994), this formula is the correct way to count the number of products for a CES consumer, in that the welfare gain to the consumer from having products in J_{ikt} that are not in J_{ik} is proportional to the log of *EM*, with the factor of proportionality depending on the elasticity of substitution between products. Hummels and Klenow (2005) were the first to refer to this formula as the extensive margin of exports.

where the right-hand side is the total exports in industry *i*, border crossing *k* and month *t*. Let us rewrite total exports as $Share_{ikt} \times Export_{kt}$, where $Share_{ikt}$ is the share of industry *i* in the total exports $Export_{kt}$ at that border crossing. Then we have the identity:

$$EM_{ikt} \times IM_{ikt} = Share_{ikt} \times Export_{kt}.$$

From this identity we specify the two regression equations:

$$\ln EM_{ikt} = \alpha_0 + \alpha_1 \ln Share_{ikt} + \alpha_2 Export_{kt} + \varepsilon_{ikt}, \tag{6}$$

and

$$\ln IM_{ikt} = \beta_0 + \beta_1 \ln Share_{ikt} + \beta_2 Export_{kt} - \varepsilon_{ikt}. \tag{7}$$

Again, by the logic of least squares, $\hat{\alpha}_0 + \hat{\beta}_0 = 0$, $\hat{\alpha}_1 + \hat{\beta}_1 = 1$, and $\hat{\alpha}_2 + \hat{\beta}_2 = 1$.

The results from these regressions are in the last two columns of Table 2. The coefficient α_1, which indicates how the extensive margin responds to the export of industry *i*, rises from 0.07 to 0.13. It remains highly significant, indicating that the extensive margin responds systematically to changes in total industry exports. The coefficient α_2 falls slightly from 0.10 to 0.09 and remains significant, indicating that the extensive margin also responds systematically to changes to overall exports at that border crossing. We conclude that the changes in the extensive margin – measured by either the number of maquiladora plants in Mexico or the range of product crossing the border – are margins of adjustment that respond at a monthly frequency. We now turn to a model that emphasizes these margins of adjustment.

III. Theoretical Model

A. Pricing and Product Variety in the Offshoring Sector

Consider a model of two countries, labeled home and foreign. The offshoring relationship in the model is characterized by the home country offshoring to the foreign country, so that home may be thought of as representing the U.S. and foreign as representing Mexico. We will scale the quantity variables coming from the foreign country by its relative size: if the share *n* of the world population resides at home and *1-n* in the foreign country, then we scale foreign quantities by *(1-n)/n*. Foreign variables will be denoted by an asterisk *.

Each country has two sectors. The first is a standard homogeneous good whose production is specific to that country; this country-specific sector will be subscripted by *H* for the home produced good and *F* for the foreign produced good, or by *X* when referring to a composite of the home and foreign homogenous goods in the consumption bundle. The second sector consists of differentiated products that are multinational, subscripted by *M*, in that they can be produced using factors in either country. This sector represents the aggregate of the four industries listed in the empirical section above, and it sometimes will be referred to as the offshoring sector. There is a continuum of products in this sector indexed by $z \in [0,1]$, and for each *z*, there is free entry of firms who then produce *N(z)* differentiated varieties of good *z*. The model follows Romalis (2004) in combining a continuum of products *z* in the *M* sector along with multiple varieties *N(z)* of each product.

Production in the offshoring sector involves a fixed cost activity as well as a variable cost activity. The fixed cost, *B*, represents headquarters and R&D services, and is paid every period. It is assumed here to be uniform across goods and takes place in the *home* country, due to the assumption that it is sufficiently more productive in these activities. The variable cost activity has a unit labor input requirement that differs by product, and follows the function $a_{Mt}(z) = \exp(az + b_t)$ in the home country. The foreign country has a corresponding function, and the relative unit-labor requirement function between the two countries will be specified as,

$$A(z) = \frac{a_{Mt}(z)}{a_{Mt}^*(z)} = \frac{\exp(az + b_t)}{\exp(a^* z + b_t^*)} = \exp(a_d z + b_{dt}),$$

where $a_d \equiv a - a^*$ and $b_{dt} \equiv b_t - b_t^*$. By ordering of the products *z*, we assume that *A(z)* is decreasing in *z*, i.e. products are arranged by increasing order of home comparative advantage, so that $a_d < 0$. It follows that those offshoring activities below some cutoff z'_t will be produced in the foreign country, while those activities above z'_t will be done at home. The cutoff activity z'_t is determined by the equality of unit-labor costs in the two countries, or given the wages W_t and W_t^*, by:

$$A(z'_t) = \frac{W_t^*}{W_t}. \tag{8}$$

Overall home-country demand in this multinational sector is specified as,

$$\ln D_{Mt} = \int_0^1 \ln d_{Mt}(z)dz, \tag{9}$$

where $d_{Mt}(z)$ is the demand for a product *z*. The market for each *z* is assumed to be monopolistically competitive, with demand for a product specified as a CES aggregate over individual varieties *i*,

$$d_{Mt}(z) = \left[\int_0^{N_t(z)} d_{Mt}(z,i)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}}.$$

The composite multinational good D_{Mt} will serve as the numeraire.

To determine the number of firms we make use of zero profits for each product *z*. Since the price of the multinational good is taken as numeraire, the revenue earned from home plus foreign sales of each variety in a symmetric equilibrium equals $[D_{Mt} + D_{Mt}^*(1-n)/n]/N_t(z)$. To obtain profits, equal to revenue minus variable costs, we divide by the elasticity of demand, σ. Setting this equal to fixed costs BW_t, we then solve for the number of products. Under our assumptions that the fixed cost and weight in demand are uniform across varieties, the number of firms likewise is uniform across varieties, so N_t does not vary with *z*:

$$N_t = \frac{D_{Mt} + D_{Mt}^*\left(\frac{1-n}{n}\right)}{\sigma BW_t}. \tag{10}$$

The overall labor demand in the multinational sector at home includes labor used for the fixed cost activity, L_{Bt}, as well as the variable cost activity, L_{Mt}, for activities not offshored ($z_t > z'_t$); labor demand abroad includes just variable cost activity for offshored activities ($z_t < z'_t$), so that:

$$L_{Bt} = N_t B = \left(\frac{D_{Mt} + D^*_{Mt}\left(\frac{1-n}{n}\right)}{\sigma W_t} \right) \tag{11}$$

$$L_{Mt} = \left(\frac{D_{Mt} + D^*_{Mt}\left(\frac{1-n}{n}\right)}{\sigma W_t} \right)(\sigma - 1)(1 - z'_t) \tag{12}$$

$$\left(\frac{1-n}{n}\right) L^*_{Mt} = \left(\frac{D_{Mt} + D^*_{Mt}\left(\frac{1-n}{n}\right)}{\sigma W^*_t} \right)(\sigma - 1) z'_t \tag{13}$$

B. Production in the Rest of the Economy

The remainder of the model follows a standard open macroeconomy specification. The country-specific sector in the home country is a perfectly competitive market for the homogeneous traded good with production function:

$$Y_{Ht} = \frac{L_{Ht}}{a_{Ht}}, \tag{14}$$

where L_{Ht} is labor in the home country-specific sector and a_{Ht} is its unit labor input requirement. Profit maximization by producers in this sector implies,

$$W_t = \frac{p_{Ht}}{a_{Ht}}, \tag{15}$$

where p_{Ht} is the relative price of the home domestic good in terms of the multinational good numeraire. Analogous conditions apply to the foreign country’s homogeneous good.

C. Households

Household preferences in the home country are represented by an instantaneous utility function of consumption (C_t), which is a composite of goods in the three sectors, and overall labor (L_t):

$$U_t = \frac{1}{1-\phi} C_t^{1-\phi} - \frac{1}{1+\mu} L_t^{1+\mu}$$

where

$$C_t = \left((1-\alpha)^{\frac{1}{\chi}} C_{Xt}^{\frac{\chi-1}{\chi}} + \alpha^{\frac{1}{\chi}} (C_{Mt})^{\frac{\chi-1}{\chi}} \right)^{\frac{\chi}{\chi-1}}$$

$$C_{Xt} = \left(\theta^{\frac{1}{\eta}} C_{Ht}^{\frac{\eta-1}{\eta}} + (1-\theta)^{\frac{1}{\eta}} C_{Ft}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}$$

In each period *t*, the economy experiences one of finitely many events, s_t. We denote by $s^t = (s_{0,} ..., s_t)$ the history of events up through and including period *t*. All variables referred to so far are implicitly functions of the states of nature in period *t* (e.g., $Y_{Ht} \equiv Y_H(s^t)$). We assume complete contingent asset markets, as discussed more fully in Chari, et al. (2002). In period *t*, consumers in either country purchase state-contingent assets in units of the numeraire good, denoted by $B_{t+1} \equiv B(s^{t+1})$, which bear a return of exactly one unit of the numeraire good in period *t+1* if state s^{t+1} occurs. They purchase these assets at the prices $V(s^{t+1} | s^t)$, which denotes the price of one unit of the numeraire good at s^{t+1} in units of the numeraire good at state s^t. The budget constraint facing the home household in period *t* is therefore:

$$P_t C_t + \sum_{s^{t+1}} V(s^{t+1} | s^t) B(s^{t+1}) = W_t L_t + B_t - G_t ,$$

where P_t is the price index of the home country consumption basket in terms of the numeraire good, and G_t is government spending. Analogous conditions apply for the foreign country.

Labor is mobile between sectors within a country, and between fixed and variable cost activities within the home offshoring sector, but there is no labor mobility between countries, meaning each country has a single but distinct equilibrium wage rate.

Households maximize the expected discounted sum of current and future instantaneous utility defined above, using the discount factor β, subject to the budget constraint.[11] The first order conditions for this problem imply the following. Risk-sharing equates nominal marginal utilities of consumption apart from a constant of proportionality,

$$\frac{P_t C_t^{\phi}}{P^*{}_t C_t^{*\phi}} = \omega, \tag{16}$$

where ω is a constant indicating the relative per-capita wealth of the home country in the initial asset allocation. Relative demands for the domestic and multinational goods are:

$$\frac{C_{Mt}}{C_{Xt}} = \frac{\alpha}{(1-\alpha)}\left(\frac{P_{Mt}}{P_{Xt}}\right)^{-\chi} \tag{17}$$

and,

$$\frac{C_{Ht}}{C_{Ft}} = \left(\frac{\theta}{1-\theta}\right)\left(\frac{P_{Ht}}{P_{Ft}}\right)^{-\eta} \tag{18}$$

where,

$$P_{Xt} = \left(\theta P_{Ht}^{1-\eta} + (1-\theta) P_{Ft}^{1-\eta}\right)^{\frac{1}{1-\eta}}.$$

Note that the law of one price holds, so the relative prices P_{Ht} and P_{Ft} apply to the goods markets in both countries. The labor supply is,

$$L_t^{\mu} = \frac{W_t}{P_t} C_t^{-\phi}. \tag{19}$$

Corresponding conditions apply for the foreign country.

D. Market Clearing and Equilibrium

Exogenous government consumption, G_t, is introduced to capture shocks to demand. It is assumed that the home government allocates demand between homogeneous domestic and differentiated multinational good in the same fashion as consumers, except that among homogenous

[11] As the discount factor β is assumed identical across countries, it cancels out of the risk sharing condition (16), and does not appear in the other equations of the model.

goods it consumes only the home and not the foreign good. This implies $G_{Mt} = \alpha\left(\frac{P_{Mt}}{P}\right)^{-\chi} G_t$,

$G_{Xt} = (1-\alpha)\left(\frac{P_{Xt}}{P}\right)^{-\chi} G_t$ and $G_{Ht} = G_{Xt}\left(\frac{P_{Xt}}{P_{Ht}}\right)$. This holds analogously for the foreign government's demand. We then define the home country demand for the multinational sector noted in the preceding section as $D_{Mt} = C_{Mt} + G_{Mt}$. The market clearing condition for the homogeneous good of home country is:

$$C_{Ht} + \left(\frac{1-n}{n}\right)C^*_{Ht} + G_{Ht} = Y_{Ht}. \qquad (20)$$

Equilibrium in the labor market requires that overall labor supply equal the sum of labor demands across sectors:

$$L_t = L_{Ht} + L_{Mt} + L_{Bt}, \qquad (21)$$

$$L^*_t = L^*_{Ft} + L^*_{Mt}. \qquad (22)$$

The general equilibrium is a sequence of 19 endogenous variables: L_t, L^*_t, L_{Ht}, L^*_{Ft}, L_{Bt}, L_{Mt}, L^*_{Mt}, W_t, W^*_t, N_t, C_{Ht}, C^*_{Ht}, C_{Ft}, C^*_{Ft} C_{Mt}, C^*_{Mt}, P_{Ht}, P_{Ft}, and z'_t, which are determined by the labor-supply condition (19), relative demand for the multinational and home country-specific goods (17) and (18), labor demand for the country-specific sector (14) and the multinational sector (12), the market clearing condition for the country-specific sector (20), the market clearing condition for labor (21), and the foreign counterparts for each of these. In addition, there is the marginal offshoring condition (8), the risk sharing condition in (16), the zero profit condition (10), labor demand for fixed cost labor (11), and the normalization of the price of the numeraire good D_{Mt} (as described in the Appendix).

E. Shocks

The model will include shocks both to demand and supply, entering through the additive demand terms (G_t and G_t^*) and the unit labor requirement terms (a_{Ht} and a_{Ft}^*). Both types of shocks are specified as first order autoregressions in log deviations from their respective means:

$$\begin{bmatrix} \log(a_{Ht}) - \log(\overline{a_H}) \\ \log(a_{Ft}^*) - \log(\overline{a_F^*}) \end{bmatrix} = \rho_a \begin{bmatrix} \log(a_{Ht-1}) - \log(\overline{a_H}) \\ \log(a_{Ft-1}^*) - \log(\overline{a_F^*}) \end{bmatrix} + \begin{bmatrix} \varepsilon_{aHt} \\ \varepsilon_{aFt} \end{bmatrix} \text{, where } \begin{bmatrix} \varepsilon_{aHt} \\ \varepsilon_{aFt} \end{bmatrix} \sim \mathrm{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \sigma_a \right)$$

and:

$$\begin{bmatrix} \log(G_t) - \log(\overline{G}) \\ \log(G^*_t) - \log(\overline{G^*}) \end{bmatrix} = \rho_G \begin{bmatrix} \log(G_{t-1}) - \log(\overline{G}) \\ \log(G^*_{t-1}) - \log(\overline{G^*}) \end{bmatrix} + \begin{bmatrix} \varepsilon_{Gt} \\ \varepsilon_{G^*t} \end{bmatrix} \text{, where } \begin{bmatrix} \varepsilon_{Gt} \\ \varepsilon_{G^*t} \end{bmatrix} \sim \mathrm{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \sigma_G \right).$$

We do not compute a separate set of Solow residuals for the offshoring sector of each country, as this might end up replicating the higher volatility in the Mexican offshoring sector in a purely mechanical way. Instead, we consider two cases of how a country's domestic productivity shocks affect the offshoring sector. One case simply assumes that productivity moves proportionately in the domestic and offshoring sectors within each country: $\tilde{a}_{Mt}(\bar{z}') = \tilde{a}_{Ht}$, $\tilde{a}^*_{Mt}(\bar{z}') = \tilde{a}^*_{Ft}$, where tildes indicate log deviations from means. This specification implies that the relative cost schedule *A(z)* shifts in response to productivity shocks. The other case differs in that it holds the *A(z)* schedule fixed, assuming that productivity shocks in a country's offshoring sector are perfectly transmitted to the other country's offshoring sector: $\tilde{a}_{Mt}(\bar{z}') = \tilde{a}^*_{Mt}(\bar{z}') = \tilde{a}_{Ht} + \tilde{a}^*_{Ft}$. This specification is similar to that assumed in Burstein et al. (2008), and is also consistent with Berman, Bound and Machin (1998) who argue that technology shocks spread quickly to other countries. We take this second specification as our benchmark, although we shall report results for the first case as well.

IV. Analytical Results

Some important intuition can be gained into relative volatilities across countries by using the labor demand conditions for the variable cost activity in (12) and (13). Denote the world demand for the multinational good as $D_{Mt}^{w} \equiv [D_{Mt} + D_{Mt}^{*}(1-n)/n]$, and replace W_t in (23) by $W_t^{*}/A(z_t^{'})$ using (8), to obtain:

$$L_{Mt} = \left(\frac{D_{Mt}^{w}}{W_t^{*}}\right)\left(1 - z'_t\right)A\left(z_t^{'}\right)\left(\frac{\sigma - 1}{\sigma}\right) \tag{23}$$

$$L_{Mt}^{*} = \left(\frac{D_{Mt}^{w}}{W_t^{*}}\right) z'_t \left(\frac{n}{1-n}\right)\left(\frac{\sigma - 1}{\sigma}\right) \tag{24}$$

We focus on the variable cost activity in these equations, as our data apply to production workers in the two countries.[12] Recalling $A(z_t^{'}) = \exp(a_d z_t^{'} + b_{dt})$ with $a_d < 0$, let us further focus on demand shocks by treating b_{dt} as constant. Then taking natural logs of (23)-(24) and using a first-order approximation for $\ln z_t^{'}$ and for $\ln(1 - z_t^{'})$, we can compute the variances:

$$\operatorname{var}(\ln L_{Mt}) = \operatorname{var}\left[\ln\left(\frac{D_{Mt}^{w}}{W_{Mt}^{*}}\right)\right] + \left[\frac{1}{(1-\bar{z}')} - a_d\right]^2 \operatorname{var}(z_t^{'}) - 2\left[\frac{1}{(1-\bar{z}')} - a_d\right]\operatorname{cov}\left[z_t^{'}, \ln\left(\frac{D_{Mt}^{w}}{W_{Mt}^{*}}\right)\right], \tag{25}$$

and,

$$\operatorname{var}(\ln L_{Mt}^{*}) = \operatorname{var}\left[\ln\left(\frac{D_{Mt}^{w}}{W_{Mt}^{*}}\right)\right] + \frac{\operatorname{var}(z_t^{'})}{(\bar{z}')^2} + \frac{2}{(\bar{z}')}\operatorname{cov}\left[z_t^{'}, \ln\left(\frac{D_{Mt}^{w}}{W_{Mt}^{*}}\right)\right]. \tag{26}$$

Thus, the variance of employment in the multinational sector depends on the variance of world demand relative to the foreign wage; on the variance of the offshoring margin $z_t^{'}$ measured *relative to* an 'adjusted' size of the offshoring sector, $\{[1/(1-\bar{z}')] - a_d\}$ at home and $(1/\bar{z}')$ abroad; and also on the covariance between $z_t^{'}$ and world demand.

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[12] The choice to exclude fixed cost labor from the U.S. total potentially works against our model's ability to generate the desired lower volatility in the U.S. But this measure is the appropriate comparison to the data, which measure employment of production workers. Simulation results are nearly identical if we include fixed cost labor, as (12)–(14) indicate that $W_t L_{Mt}$ is proportional to $W_t(L_{Mt} + L_{Bt})$, including fixed costs at home, for fixed z'.

The covariance term in (25)-(26) will generally be positive for home demand shocks, since an increase in home demand raises the offshoring margin $z_t^{'}$ but also lowers the foreign wage W_t^*.[13] Notice that the covariance enters with a *positive* sign in (26) but a *negative* sign in (25): as more offshoring activities are shifted abroad, that will tend to offset the variance in home employment in the offshoring industry, but enhance it abroad, because the procyclical nature of $z_t^{'}$ will amplify the impact abroad of the demand shocks. Therefore, a positive covariance between world demand for the multinational good and the offshoring margin will shift variance towards the foreign country. This situation is clearly relevant for the U.S./Mexico case we study, as the U.S. is the primary demander for offshored goods both in the data and in our simulation due to its larger population and wealth.

The volatility in employment also depends on the size of the offshoring sector in the two countries, adjusted by $a_d < 0$ which determines the slope of the $A(z)$ schedule. Provided that $\{[1/(1-\bar{z}')] - a_d\} < (1/\bar{z}')$, which is easily satisfied in our calibration, then the volatility of employment in the foreign country will magnified by the variance in $z_t^{'}$. This occurs simply because the shift of a given amount of employment from home to foreign will have a greater *percentage* impact abroad when the foreign country has a smaller offshoring sector. So for this reason, also, the foreign country will experience greater volatility.

Our model also includes supply shocks in the two countries, but their impact is sensitive to how the shocks are specified. In our benchmark case we hold fixed the *A(z)* schedule. In that case, supply shocks in the homogeneous goods turn out to have minimal impact on the offshoring margin *z′*, relative wages, or other endogenous variables. This finding follows from a little-known result in the international macro literature. Consider our model without the offshoring sector, so that it is a two-good Ricardian model with complete asset markets, and assume Cobb-Douglas preferences over the

[13] With b_{dt} constant, it is readily shown from (A3) in the Appendix that any increase in the home wage due to demand shocks must be matched by a decrease in the foreign wage, since both are measured relative to the price of the multinational good which is the numeraire. Therefore, home demand shocks raise W_t and lower W_t^*.

homogeneous goods from each country. Then it turns out that the technology shocks have no impact at all on relative wages. The reason is that a positive productivity shock to, say, the home good, will reduce its price on international markets but increase its demand by the same percentage amount, so the implied relative labor demand across countries is unchanged. Relative labor supply is also unchanged due to complete asset markets, so the equilibrium relative wage does not change.[14] Adding the offshoring sector but with a fixed *A(z)* schedule leads to nearly the same result.

However, when we allow the *A(z)* schedule to respond to technology shocks, then a rise in home productivity shifts the *A(z)* schedule down compared to a given relative wage, inducing a fall in offshoring. This "in-sourcing" behavior implies a negative correlation between employment in the home and foreign offshoring activity, and is counterfactual given the positive correlations observed in the data. This is one benefit of using our benchmark specification of productivity shocks, where the *A(z)* schedule is held fixed by assuming transmission of productivity across countries within the offshoring sector.

V. Numerical Experiment

A. Calibration

We calibrate the model to monthly data for the U.S. and Mexico. Parameter choices are summarized in Table 3. We have already argued that the magnitude of $\bar{z}'$ is important. Taking the ratio of (12) and (13) indicates that $\bar{z}'$ can be calibrated to match the Mexican share of production labor earnings in the offshoring sector.

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[14] The result that neutral technology shocks have no impact on the relative wage in a two-sector model with large countries and Cobb-Douglas preferences is noted by Krugman (2000), in a model with fixed labor endowments. Using labor choice and complete asset markets, Devereux and Engel (2001) obtain a factor-price equalization result under the assumption that labor enters the utility function linearly. Our assumptions are weaker, since labor enters utility with a power. Combining (16) and (19) we readily obtain $(L_t / L_t^*)^{\mu} = (W_t / W_t^*)$, which is the relative labor supply schedule. Relative labor demand in the two-sector Ricardian economy is obtained by combining (14) with Cobb-Douglas preferences , $L_{Ht} / L_{Ft} = a_{Ht} Y_{Ht} / a_{Ft} Y_{Ft} = (a_{Ht} / a_{Ft})(p_{Ft} / p_{Ht})$. Then substituting for prices from (15) we have, $L_{Ht} / L_{Ft} = (a_{Ht} / a_{Ft})(a_{Ft} W_{Ft} / a_{Ht} W_{Ht}) = (W_{Ft} / W_{Ht})$. This proves that both relative labor demand and supply do not depend on the technology shocks, so neither does the equilibrium relative wage.

$$\frac{(1-n)W_t^* L_{Mt}^*}{nW_t\ L_{Mt}} = \frac{z_t^{'}}{1-z_t^{'}} \qquad (27)$$

Averaging over our data for earnings in the four offshoring industries at the end of our sample indicates a share of 0.06.

The U.S. unit cost schedule in the offshoring sector is characterized by the two parameters, a and the mean of b. First, we calibrate the level of this schedule at the steady state margin to be the same as for the overall U.S. manufacturing sector, which is normalized to unity (that is, $a_M(\bar{z}') \equiv \exp(a\bar{z}'+b) = \bar{a}_H = 1$). Second, we replicate the observation in Bernard et al. (2003) that the standard deviation of log U.S. plant sales is 1.67. This is sufficient to pin down both schedule parameters.[15]

Similarly, two pieces of information are needed to pin down the two parameters a_d and b_d in the cross-country relative unit cost schedule, $A(z_t) = \exp(a_d z_t + b_{dt})$. First, we calibrate the level of this schedule at the steady state offshoring margin to our data. The average weekly rate of payment to workers for the four offshoring industries in the data set is 8 times higher in the U.S. than in Mexico, implying that $A(\bar{z}')=1/8$ (and hence $\bar{b}_d = \ln(0.125) - a_d\bar{z}'$). Secondly, we calibrate the slope of the schedule at the steady state margin, by using estimates from Eaton and Kortum (2002) of the variation within the distribution of productivity across a continuum of goods.[16] They show that their distribution implies a relative distribution of unit labor input requirements across two countries of $A(z) = (T_1/T_2)^{1/\theta}[(1-z)/z]^{1/\theta}$, where θ is the parameter characterizing variation in the distribution within the continuum of goods, and T_1 and T_2 characterize the absolute technology advantage of the countries over the whole continuum. This is analogous to the relative cost schedule of Dornbusch et

[15] In particular, given that the schedule is defined over the unit interval, and if we identify firm size with sales, which depends on price and the elasticity σ, the constant value a can be computed as $-1.67(12)^{0.5}/\sigma$. Then b_t varies with overall productivity shocks as $b_t = \log(a_{Ht}) - a\bar{z}$.

[16] Their estimates are based upon bilateral import shares and price differences for 50 manufactured products, most of which coincide with offshoring industries.

al. (1976), and thereby analogous to our own *A(z)* schedule. Given their preferred estimate of θ at 8.28, and since the ratio T_1/T_2 is pinned down by our calibration above that $A(\bar{z}')=1/8$, this is sufficient information to pin down the desired slope as $A'(\bar{z}')=-0.2677$, and hence $a_d = A'(\bar{z}')/A(\bar{z}') = -2.14$.

The fixed cost, *B*, enters the model only jointly as a product with *N*, the number of firms, where *NB* represents the total fixed costs paid by an industry in labor units. Domowitz, et al. (1988) report estimates of the size of fixed costs for a range of U.S. industries as a share of industry output. Three of these correspond to the industries we use (apparel, electronic equipment, and transportation equipment), and the average among these indicates a share of 0.11. Equations (10) and (12) imply that this share can be written as $WBN/WL_M = 1/[1+(\sigma-1)(1-\bar{z}')]$. Given calibration of $\bar{z}'$ above, matching the fixed cost share necessarily pins down the calibration of σ at 9.5.

The relative wealth parameter ω is chosen to imply a ratio of per-capita consumption of the U.S. to Mexico in steady state that matches the data, which the Penn World tables indicate is 4.3 in 2000. The parameter *n* is calibrated to reflect the 74 percent share of the U.S. in the combined population of the two countries. Calibrations of standard preference parameters are taken from the business cycle literature. The labor supply elasticity is set at unity, μ=1. The curvature parameter is set at ϕ=2. The elasticity of substitution between home and foreign goods is calibrated at the common value of unity, $\eta=1$.[17] We assume a higher elasticity, χ=2, between the homogeneous and multinational good.

The remaining preference parameters are calibrated to reflect the relationship between U.S. and Mexican aggregates. The home bias parameters reflect the share of import expenditures in GDP, θ=0.88, θ^*=0.71. The four U.S. industries classified as offshoring industries in the data set represent 24% of total U.S. manufacturing, so the offshoring share parameter is calibrated at $\alpha=0.24$. The

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[17] Bergin (2006) estimates a value near unity for this elasticity using macroeconomic data.

relative weight on the home country in the complete asset market allocation (ϖ) is calibrated to replicate the ratio of U.S. to Mexican per capita consumption. The steady state levels of the additive consumption terms ($\overline{G}$ and $\overline{G^*}$) are calibrated at 15% of total demand, representing the share of government purchases in U.S. gross national expenditure during our sample range.

The mean unit labor requirement in Mexico's domestic sector ($\overline{a}_F$) is calibrated to imply a steady state of the model consistent with the assumption above that the Mexican wage is 1/8 that of the U.S. Productivity shock parameters are estimated from a first-order autoregression on Solow residuals, computed from monthly manufacturing data from our sample range.[18] Regarding demand shocks, since there is no monthly series available for government consumption, total government spending from IFS is used. Linear trends are removed from the log of each series before fitting it to the first-order autoregressive processes used for all shocks above. See Table 3 for exact values.

B. Numerical Results

Simulations consist of solving the model numerically in its original nonlinear form for 120 periods of random draws of shocks. The first 20 periods are dropped, and the remaining 100 periods are HP filtered and used to compute moments. This process is repeated 1000 times, and we report the average of moments over the replications. These simulated moments are compared to the moments for actual data computed in Bergin, Feenstra and Hanson (2009).

Results for the benchmark case of the model are summarized in column (2) of Table 4; actual moments for Mexico and the U.S. are in column (1). Although the focus of our study is on the offshoring sector, it is reassuring for our general calibration of shocks that the volatilities for overall manufacturing employment are in the neighborhood of what is observed in the aggregate data, including the fact that overall employment volatility is somewhat higher in the U.S. than in Mexico.

[18] We follow the convention in Glick and Rogoff (1995) of computing Solow residuals by setting the labor share at 0.6 and assuming a constant capital stock. Resulting estimates are almost identical if we assume a labor share of unity, as implied by the production function in the model above.

Of primary interest is the fact that the calibrated model can easily generate double the volatility in the offshoring sector of Mexico relative to the corresponding U.S. sector. The standard deviation of employment for Mexican offshoring, 4.5%, is remarkably close to that in the data at 4.4%; the employment volatility in U.S. offshoring is somewhat underestimated compared to the data, 1.5% and 2.0%, respectively.[19]

We next evaluate the model's implications for extensive margin movement. For a measure of the standard deviation of $z_t^{'}$, we use the number of HS products exported from Mexico, which averaged 3.6%. A somewhat smaller number of 2.9% is obtained in the benchmark simulation. This indicates that our explanation for Mexican volatility does not rely upon an unreasonably high degree of firms switching their offshoring decision. Further evidence on the extensive margin comes from Bergin, Feenstra, and Hanson (2009), who present data on the number of plants operating each month in the maquiladora sector. The monthly standard deviation in the number of plants (logged, deseasonalized and HP filtered) ranged between 2.1 percent for electrical machinery to 5.2 percent for apparel, with an average of 3.1 percent over the four industries. These results can be compared to the theoretical model either as the number of plants N_t, or to $N_t z_t^{'}$, which is the product of plants per good and the mass of offshored goods. The standard deviations for N_t and $N_t z_t^{'}$ implied by the model simulation encompass the standard deviation on the number of plants from the data.[20]

Regarding employment correlations, all are positive as in the data, indicating positive comovement between the offshoring sectors of both countries. This coincides with our intuition provided earlier, for how demand shocks in particular should generate volatility in the Mexican

[19] The model does not replicate the volatility of the wage-based real exchange rate across countries, however. The standard deviation of log W^*/W in the simulation is 0.48; in data, the standard deviation of log sw^*/w, where s is the nominal exchange rate and w and w^* are wage indexes from IFS, is 4.22 for our sample range. The failure to explain volatility of real exchange rates of various types is common to our class of models that exclude nominal shocks and nominal rigidities. This property is not a result of endogenous offshoring dampening relative wage volatility, as the volatility of the relative wage is likewise small, 0.87, when we suspend the A(z) schedule and hold z' fixed.

[20] If the maquiladora plants all produced a single product, then it would be appropriate to measure their number by $N_t z_t^{'}$; but if the plants all produce the full range of products, then their number should be measured by N_t.

offshoring sector.[21] Our model has a somewhat stronger correlation of the range of products $z_t^{'}$ with U.S. employment than obtained from the data, however.

At the bottom of Table 4 we report the theoretical covariance between $z_t^{'}$ and $\ln(D_{Mt}^{w}/W_t^{*})$. That covariance is positive in our benchmark results in column (2), reflecting the procyclical nature of the extensive margin of offshoring. From our results in (25)-(26), that positive covariance combined with the smaller size of the offshoring sector in the foreign country ($\bar{z}'$ = 0.06), both contribute to higher volatility of employment abroad.

Columns (3)-(6) indicate the results obtained when just one of the four shocks is used. These results reveal that the home demand shock is the most important driver of the amplified volatility in the Mexican offshoring sector. Column (7) confirms the analytical claim above that our main result depends crucially on endogenous movement in the offshoring margin. Mexican employment volatility falls to a level much closer to the U.S for offshoring sector earnings when z' is held fixed.

The theoretical model did not attempt to represent the complex dynamics of firm entry, in which it is reasonable to think there are substantial delays between a decision to enter and actually commencing production. Nor does the theory model the sunk cost of entry, which might discourage entry in response to transitory shocks. We test whether the modeling of this feature could be quantitatively relevant for the issue at hand, by modeling it in its most extreme form. Column (8) of Table 4 reports simulation results for the case where the number of firms is held constant. The results are almost the same as the benchmark case. Since modeling the most extreme form of sluggishness in firm entry has a quantitatively small impact on the results, it would seem that modeling the intermediate cast of realistic entry dynamics is not warranted. One might also consider modeling an adjustment cost discouraging switching in the offshoring decision, which is more likely to affect our

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[21] Note that a positive demand shock in the U.S. has two effects: the rise in demand directly raises firm entry and employment in the U.S., but at the same time the rise in relative wage induced by the shock leads some entry and employment to be shunted to Mexico.

results, given that endogenous movement in the offshoring sector is behind the cross-country difference in volatilities. But given that the standard deviation of the offshoring margin in our benchmark case is close to that in the data, there appears to be no empirical motivation for introducing such an adjustment cost in this model.

When the relative productivity schedule *A(z)* is made flatter, where the slope $A'(\bar{z}') = -0.1$, column (9) shows that Mexican volatility rises. A flatter distribution implies greater movement in the offshoring margin *z*.

As the analytical result identified the mean of the offshoring margin as important for our result, column (10) reports results for the case of an equal split of goods between the U.S. and Mexico, $\bar{z}' = 0.5$. In this case there is much less volatility in the foreign offshoring sector than found with our benchmark calibration, though volatility there still exceeds that found in the home offshoring sector. The reason why foreign volatility is higher even with equal-sized offshoring industries in the two countries is that the covariance between $z_t^{'}$ and $\ln(D_{Mt}^{w} / W_t^{*})$ still adds to the volatility of employment abroad, but offsets it at home, as shown by (25)-(26).

Finally, we study alternative specifications of the supply shock that are allowed to shift the *A(z)* schedule in the offshoring sector, as discussed previously. In column (11) this is found to further amplify the volatility in the Mexican offshoring sector to remarkably high values. But this comes at the cost of implying strong negative correlations between the offshoring sectors of both countries. This arises from the fact, as discussed previously, an increase in U.S. relative productivity exceeding the increase in the U.S. relative wage induces U.S. firms to "in-source" activity previously allocated to Mexico.

VI. Conclusions

Global production sharing is responsible for a substantial portion of world trade and is the primary means through which many developing countries engage in international commerce. While the expansion of export assembly operations have lead to impressive rates of employment growth in China, Eastern Europe, Mexico, and elsewhere, the implications of global production sharing for the volatility of economic activity has only recently attracted scholarly attention. In the case of Mexico, the country's offshoring industries experience fluctuations in economic activity that are twice as volatile as the corresponding industries in the U.S. (Bergin, Feenstra, and Hanson, 2009). In this paper, we find that fluctuations in offshoring employment in Mexico result in part from adjustment at the extensive margin, as products enter and exit trade between the two countries.

To account for differences in U.S. and Mexican employment variability, we develop a theoretical model in which heterogeneous firms in a high wage country (the U.S.) are free to enter and exit offshoring relationships with firms in a low wage country (Mexico). Shocks that change U.S.-Mexico relative wages induce U.S. firms to alter which products they offshore to Mexico. Adjustment in the offshoring margin is the main mechanism through which U.S. shocks become amplified in Mexico. Stochastic simulations show that the model matches the empirical regularities observed in U.S. offshoring to Mexico. For Mexico, one consequence of economic integration with the U.S. appears to be greater variability in its manufacturing employment.

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Appendix

Labor demand at home is obtained by integrating over the fixed costs *B* for every product $z \in [0,1]$, and the variable labor input requirement $a_{Mt}(z)y_t(z)$ for those products $z \in [z'_t, 1]$:

$$L_t = \int_0^1 BN_t dz + \int_{z_t'}^1 a_{Mt}(z)y_t(z)N_t dz \,. \qquad \text{(A1)}$$

The number of varieties N_t appearing in the first integral of (A1) is obtained from (10). For the second integral, we multiply the labor input requirement $ay_t(z)$ by the wage W_t, and further multiply by the markup $\sigma/(\sigma-1)$, to obtain the expenditure $[C_{Mt} + C^*_{Mt}(1-n)/n]/N_t$ on each variety. So the expression inside the second integral of (A1) equals $[C_{Mt} + C^*_{Mt}(1-n)/n](\sigma-1)/\sigma W_t$, which is integrated over $z \in [z_t', 1]$ to yield (11).

For foreign labor demand we integrate the variable labor input requirement $a^*_{Mt}(z)y^*_t(z)$ for $z \in [0, z_t']$:

$$L^*_t = \int_0^{z_t'} a^*_{Mt}(z)y^*_t(z)N_t dz \,. \qquad \text{(A2)}$$

Multiplying the labor input requirement $a^* y^*_t(z)$ by the wage W^*_t, and further multiplying by the markup $\sigma/(\sigma-1)$, we again obtain the expenditure $[C_{Mt} + C^*_{Mt}(1-n)/n]/N_t$ on each variety. So the expression inside the integral of (A2) equals $[C_{Mt} + C^*_{Mt}(1-n)/n](\sigma-1)/\sigma W^*_t$, which is integrated over $z \in [0, z'_t]$ to yield (12).

Finally, the price index for multinational goods is:

$$\ln P_{Mt} = z'_t \ln W^*_t + (1-z'_t)\ln W_t + \ln\left(\frac{\sigma}{\sigma-1}\right) + \left(\frac{a^*-a}{2}\right)(z'_t)^2 + \left(b^*_t - b_t\right)z'_t + \frac{a}{2} + b_t \,, \qquad \text{(A3)}$$

is set equal to unity to close the model.

Table 1: U.S. Harmonized System Imports from Mexico, 1996–2006

	Apparel	Electrical Machinery	Computer & Electronics	Transport Equipment
Laredo, TX				
Mean Number of HS Products	384.0	219.2	258.6	140.5
Mean Number of Months a HS Product is Imported Per Year[a]	6.9	8.9	7.5	9.0
Std. Dev. Log Number of HS Products[b]	2.64	2.14	3.10	2.94
Correlation of Number of HS Products and U.S. Manufacturing Employment[c]	0.28	0.32	0.07	0.31
El Paso, TX				
Mean Number of HS Products	162.6	137.0	208.3	53.4
Mean Number of Months a HS Product is Imported Per Year[a]	5.8	8.9	7.8	7.8
Std. Dev. Log Number of HS Products[b]	4.99	2.43	2.60	5.66
Correlation of Number of HS Products and U.S. Manufacturing Employment[c]	0.05	0.04	0.12	0.30
San Diego, CA				
Mean Number of HS Products	299.8	129.6	237.0	53.2
Mean Number of Months a HS Product is Imported Per Year[a]	6.3	8.3	7.5	7.0
Std. Dev. Log Number of HS Products[b]	3.38	3.86	3.39	6.18
Correlation of Number of HS Products and U.S. Manufacturing Employment[c]	-0.01	0.28	0.25	0.12

Notes:
a. Averaged over HS products and over the years 1996–2006.
b. The log number of HS products has been deseasonalized and HP filtered, and the standard deviation is multiplied by 100.
c. The number of HS products and U.S, manufacturing employment are in logs, and are deseasonalized and HP filtered.

Source:
Bureau of the Census, 1996-2006, *U.S. Exports and Imports of Merchandise on CD-ROM* [machine-readable data file], Washington, D.C.

Table 2: Adjustment in the Maquiladora Industry: Extensive Margins

	(1) No. of HS Products	(2) Sales per HS Product	(3) Extensive Margin of Exports	(4) Intensive Margin of Exports
Industry share of exports	0.071	0.929	0.131	0.869
at border crossing	(0.021)	(0.021)	(0.025)	(0.025)
Total exports	0.103	0.897	0.085	0.915
at border crossing	(0.027)	(0.027)	(0.025)	(0.025)
R^2	0.02	0.77	0.04	0.70
N	1584	1584	1584	1584

Notes:

Columns (1) and (2) show regressions of either the number of HS products imported by the U.S. per month, or the average import sales per HS product, on the industry share of imports at that border crossing and total imports from Mexico at that border crossing. Columns (3) and (4) show regressions of the extensive margin of Mexican exports (which is a weighted count of the number of HS products) and the intensive margin of Mexican exports (which is the industry sales divided by the extensive margin), on the same independent variables. The sample is the four offshoring industries in Mexico, exporting to three land border crossings, with data at a monthly frequency from 1996:1 to 2006:12. All variables are in logs, expressed in real terms, deseasonalized, and HP filtered. All regressions include controls for industry fixed effects, which are not shown. Standard errors (clustered by industry) are in parentheses.

Table 3. Calibration of model Parameters

Preferences

θ	home bias in U.S.	0.88
θ^*	home bias in Mexico	0.71
α	offshoring expenditure share	0.24
σ	elasticity between varieties	9.5
η	elasticity, multinational and domestic goods	1
χ	elasticity, home and foreign goods	2
μ	labor supply elasticity	1
ϕ	risk aversion	2
n	relative size of U.S.	0.74
ϖ	relative wealth of U.S.	24.5
$\overline{G}$	US mean government demand	0.186
$\overline{G^*}$	Mexican mean government demand	0.0432

Technology

$\overline{a_H}$	US steady state unit cost	1
$\overline{a_F^*}$	Mexican steady state unit cost	4.22
$\bar{z}'$	offshoring margin	0.06
a	US offshoring slope parameter	-0.609
$\overline{b}$	US offshoring level parameter	0.0365
a_d	relative cost slope parameter	-2.14
$\overline{b_d}$	relative cost level parameter	-1.95

Shock processes

$$\sigma_a = \begin{bmatrix} 6.42x10^{-5} & -4.67x10^{-6} \\ -4.67x10^{-6} & 1.87x10^{-4} \end{bmatrix} \qquad \rho_a = \begin{bmatrix} 0.931 & -4.02e-2 \\ 7.38e-3 & 0.961 \end{bmatrix}$$

$$\sigma_G = \begin{bmatrix} 7.68x10^{-3} & 4.02x10^{-3} \\ 4.02x10^{-3} & 2.36x10^{-2} \end{bmatrix} \qquad \rho_G = \begin{bmatrix} -0.0549 & 0.379 \\ -0.368 & 0.424 \end{bmatrix}$$

Table 4. Model Simulation for Production Worker Employment in the Offshoring Sector

	(1) Mexican or U.S. data	(2) Benchmark case	(3) U.S. demand shock	(4) Mexico demand shock	(5) U.S. supply shock	(6) Mexico supply shock	(7) Fixed z'	(8) Fixed *N*	(9) Flatter *A'(z)*[b]	(10) $\overline{z'} = 0.5$[c]	(11) Altern. supply Shocks[d]
Standard deviations (%):											
$\sigma(L^*_M)$	4.44	4.54	3.80	2.63	0.59	1.86	2.15	4.45	5.63	1.40	12.89
$\sigma(L_M)$	2.04	1.52	0.59	0.56	0.27	1.21	1.62	1.56	1.46	0.76	1.22
$\sigma(L^*)$	0.89	0.94	0.48	0.57	0.39	0.26	0.88	0.93	1.02	1.00	1.28
$\sigma(L)$	1.15	1.22	0.90	0.66	0.44	0.20	1.24	1.20	1.21	1.17	1.20
$\sigma(L^*_M)/\sigma(L_M)$	2.21	3.01	6.45	4.77	2.15	1.54	1.34	2.90	3.90	1.85	10.66
$\sigma(L^*)/\sigma(L)$	0.77	0.77	0.53	0.87	0.90	1.29	0.71	0.78	0.84	0.85	1.07
Correlations:											
$corr(L^*_M, L_M)$	0.51	0.73	0.98	0.36	1.00	1.00	0.96	0.72	0.61	0.83	-0.35
$corr(L^*, L)$	0.78	0.93	0.99	0.86	1.00	0.96	0.81	0.93	0.98	0.99	0.71
$corr(L^*_M, L^*)$	0.64	0.46	0.97	0.19	1.00	-0.79	0.27	0.45	0.58	0.93	0.78
$corr(L_M, L)$	0.76	0.50	1.00	0.94	0.99	-0.62	0.56	0.49	0.45	0.78	0.73
$corr(z', L)$	0.18	0.71	0.99	0.49	1.00	-0.55	0.00	0.70	0.71	0.84	0.23
Margin movements (%):											
$\sigma(z')$	3.61	2.86	2.58	1.99	0.25	0.53	0.00	2.79	4.15	0.54	13.10
$\sigma(N)$	3.14 (for $\sigma(N)$ and $\sigma(N z')$)	1.66	0.80	0.61	0.30	1.25	1.62	0.00	1.68	0.82	1.12
$\sigma(N z')$		4.09	3.37	2.31	0.55	1.77	1.62	2.79	5.34	1.22	13.50
Addendum: covariance ($x10^4$)											
$cov(z', D_W/W^*)$[a]		0.33	0.25	0.09	0.01	0.06	0.00	0.32	0.50	0.07	-0.30

Notes:

[a] All variables are in logs except for z' in this expression.

[b] *A'(z)* = -0.1.

[c] Holding the slope *A'(z)* constant at its benchmark value of -0.2677.

[d] *A(z)* distribution shifted by productivity shocks.

Figure 1: The Number of HS Products Over Years
(Ave. over 3 ports; Log values, seasonally adjusted, HP filtered)