International Business Cycles - The Role of Technology and Resource Transfers Via Multinationals

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Abstract

I develop a general equilibrium model of trade and multinational production (MP) with firm heterogeneity, market access frictions including a MP sunk cost, technology transfer from multinational parent to affiliate, and physical capital. There is a novel "resource transfer" channel as MP firms enter and exit over the business cycle with their capital. Compared to the resource transfer channel in standard trade models such as Backus et al. [1994], the new channel via multinationals leads to faster capital relocation across countries, which generates greater macroeconomic volatility. Technology transfer within MP firms dampens the effect of the novel resource transfer channel by altering the MP-exporter trade-off. A model calibrated to the United States generates output and net exports volatilities, persistence of most variables, and international consumption correlation closer to the data compared to the no-MP model.

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1 Introduction

How does multinational production (MP), where some firms produce in multiple countries, affect international real business cycles (IRBC)? The theoretical research on this is limited (with the exceptions of Contessi [2010, 2015], Zlate [2016]), in spite of the fact that affiliates sales as a share of world gross domestic product (GDP) grew eight-fold in between 1990 and 2007 (Ramondo [2014]). Instead, theoretical IRBC research is tilted towards evaluating exports, which as a share of world GDP grew only 19% during the same period, as a driver of aggregate business cycle dynamics.[1] Furthermore, recent empirical evidence shows that multinationals are important channels for cross-border spillovers (di Giovanni and Levchenko [2010], Cravino and Levchenko [2017], di Giovanni et al. [2017, 2018], Boehm et al. [2020]). For example, Cravino and Levchenko [2017] find that there is a 20% comovement between headquarter and affiliate sales, and conclude that external shocks transmitted via multinationals contribute to 10% of aggregate productivity fluctuations. Similarly, di Giovanni et al. [2017] find that direct ownership linkages at the firm level have macro implications.

In this paper, I evaluate how aggregate dynamics are affected by MP by extending a real business cycle model with heterogeneous firms and trade to include multinational firms. The goal is to address the main weakness in quantitative trade models (i.e., the absence of MP) and in quantitative MP models (absence of one or more important features; see below). By doing so, this paper provides a new perspective to the quantitative models going back to Backus et al. [1994] that attempt to replicate observed relationships between high frequency business cycle variables.

The empirical research on multinationals and business cycles has uncovered the following regularities in the data. These facts serve as guideposts while developing the quantitative MP model. First, even among firms that sell to foreign markets (i.e., exporters and MP firms), multinationals typically belong to the larger firm size category (Doms and Jensen [1998]). Second, there is a non-zero annual transition probability into and out of MP status. Boehm et al. [2020] estimate average annual MP entry and exit rates of 0.295% and 2.37% respectively.[2] Although these probabilities are not large in absolute value, these transitions can be quantitatively important given the larger size of the MP firms. For reference, quantitative trade models typically target exporter entry and exit rates of around 12-14% per annum and find the extensive margin of exporters to be quantitatively important. Third, multinational affiliate and headquarter sales move together, which is interpreted to be a consequence of headquarter to affiliate technol-

[1] Quantitative trade models have attempted to replicate the observed business cycle moments including (but not limited to) cross-country output correlation and the real exchange rate-net exports relationship. See Backus et al. [1994], Ghironi and Melitz [2005], Kose and Yi [2006], Alessandria and Choi [2007], Johnson [2014], and Liao and Santacreu [2015].

[2] I remove firm exit while calculating these transition rates. I explain this in detail in Appendix B.

ogy transfer (Cravino and Levchenko [2017]).[3] Fourth, multinationals between developed economies are of "horizontal" nature wherein MP affiliates substitute trade (Markusen [1995], Swenson [2004]) as opposed to cheaper-labor-seeking vertical MP observed between developed and developing economies.

I incorporate these features in to the Alessandria and Choi [2007] model of heterogeneous firms and market access frictions augmented to include MP. Firms differ by their productivity, own their physical capital stock, and are subject to aggregate and idiosyncratic shocks to their total factor productivity (TFP). Market access frictions, modelled as fixed export cost and fixed and sunk MP costs, reduce firms' profits from engaging in these activities.[4] This results in a segregation of firms into domestic, export, and MP based on their idiosyncratic productivities and last-period MP status. On average, in the cross section, the most productive firms conduct MP, firms with intermediate productivities export, and the least productive firms serve only the domestic market. In addition to this cross sectional separation, the sunk MP cost adds persistence to firms' MP status. Over time, a firm's status changes as the aggregate shocks shift the entry and exit productivity thresholds and as its idiosyncratic TFP changes. In sum, a firm's status is a function of current macroeconomic conditions, its idiosyncratic productivity, and its past MP status.

I model technology transfer in the following way. Cravino and Levchenko [2017] estimate that 20-40% of affiliate productivity comes from the headquarters. I mimic this by following a combination of approaches in existing quantitative MP models (Contessi [2010, 2015] and Zlate [2016]) and Cravino and Levchenko [2017]. The quantitative MP models assume that affiliate idiosyncratic productivity is the same as that of its parent (i.e., full transfer of idiosyncratic productivity) while the aggregate productivity is that of the host country (i.e., zero transfer of aggregate productivity). I allow for a partial transfer (governed by a technology transfer parameter) of the parent country's aggregate shock to the affiliate in addition to the full transfer of headquarter idiosyncratic productivity.

The model improves on the quantitative MP model in Contessi [2010] along four dimensions. First, I incorporate sunk cost of conducting MP wherein non-MP firms must pay an upfront cost of entering the foreign market as an MP firm. This corresponds to the high observed setup costs involved in becoming multinationals. The sunk cost allows me to match MP transition rates to the data. Second, there is physical capital in the model which, due to time taken to accumulate capital, leads to delayed response functions. Third, the labor supply is endogenous and responds to fluctuations in aggregate

[3]This paper only focuses on technology transfer *within* multinationals - i.e., from parent to affiliates. I do not explicitly model the well documented spillovers from affiliates of multinationals to local firms in the host country.

[4]Alessandria and Choi [2007] show that export sunk cost has negligible impact on business cycle dynamics, so I do not model this cost.

wages unlike in Contessi [2010] where it is fixed. Allowing labor supply to vary is key to matching the observed response of real exchange rate and wages to productivity shocks. Fourth, there is technology transfer via MP firms as described above, which generates shock spillover through these firms.

This paper focuses on how the technology and resource transfer channels via multinationals interact to alter business cycle dynamics. These channels are driven by affiliates' entry and exit. As a new affiliate is set up, it brings some capital from its parent (resource transfer via MP) and it brings its own idiosyncratic technology along with home country's aggregate technology. The impact of the two channels can be summarised as follows. Compared to the no-MP model, the resource transfer channel via MP makes macro variables less correlated across countries and more volatile; the technology transfer channel dampens the resource transfer channel.

One can understand these results by tracing impulse responses to a positive aggregate shock in one country (Home). On the one hand, exporting (MP) becomes more attractive for Home (Foreign) firms relative to MP (exporting) as Home effective wage rate falls. On the other hand, technology transfer makes MP (exporting) more attractive as Home (Foreign) firms can carry their productivity advantage (disadvantage) abroad. The impact on the number of MP firms is a result of these two opposite forces. In the net in the calibrated model (described below), technology transfer channel is not powerful enough to overcome the cheaper production cost in Home. As a result, there is an increase in the number of affiliates in Home and a decrease in Foreign. In a business cycle sense, there is greater volatility in the number of firms and capital stock in each country which translates to greater macroeconomic volatility. There is less correlation of output, consumption, investment, and employment across countries. In a zero technology transfer regime, as the force of cheaper Home wage is not counteracted, there is even greater macroeconomic volatility. The international correlations are also lower in the zero technology transfer regime.

It is relevant to compare the MP resource transfer mechanism explained above with the resource transfer mechanism in trade models (see Kose and Yi [2006]). The resource transfer mechanism in trade models goes through net exports and is gradual: Home households borrow internationally to invest more while Foreign households lower their investments, and the two capital stocks diverge for some quarters (after which they converge towards steady state). In contrast, the movement of capital via MP firms does not impact net exports, and it leads to faster initial capital stock divergence. In other words, the MP resource transfer channel augments the channel present in trade models.

To quantify these mechanisms, I calibrate the model to match the United States (US) business cycle at quarterly frequency. I set the technology transfer level to a value estimated in Cravino and Levchenko [2017]. They estimate a value between 20-40%, so I take a mid-point of 30% in the benchmark simulations. A trade-only model is used for comparison. While all macro variables with the exception of consumption are more volatile under benchmark calibration, for output and net exports higher volatility makes the model closer to data by 21% and 10% respectively. Furthermore, the MP model generates investment-output correlation and international consumption correlation closer to the data by 20% and 9.5% respectively. Overall, eleven of the 22 macro moments tracked are closer to the data in the MP model while eight are farther from the data.

The main contribution of this paper is to build a model of MP that brings together different features of the data. Its motivation is similar to Contessi [2010] in looking at the effect of horizontal multinational activity on international business cycle moments. The MP model here is an improvement on four dimensions as explained above. In particular, there is: i. a sunk cost of MP, ii. MP parent to affiliate technology transfer, iii. endogenous labor supply, and iv. physical capital. In contrast to this paper and Contessi [2010], Zlate [2016] looks at the effect of north-south type of vertically fragmented MP and its effects on international business cycles. His paper is motivated by the US-Mexican maquiladora relationship where US multinationals produce in Mexico, but the affiliate output is shipped back to the US. This type of MP increases output comovement across countries because there is a direct spillover of US demand on production in the maquiladoras. My paper focuses on the effects of the more dominant type of MP between high-income countries (i.e, of the north-north type) and its effect on international business cycles. This paper also contributes to the expanding literature the effect of MP on business cycle dynamics (see Budd et al. [2005], Buch and Lipponer [2005], Desai and Foley [2006], Burstein et al. [2008], Desai et al. [2009], Contessi [2010, 2015], Kleinert et al. [2015], Zlate [2016], Cravino and Levchenko [2017], di Giovanni et al. [2018], and Boehm et al. [2019]).

The rest of the paper is organized as follows - Section 2 proposes a business cycle model with heterogeneous firms, trade, and horizontal MP; Section 3 details the calibration procedure; Section 4 provides the results and intuition, and Section 5 concludes.

2 Model

In this section, I develop a model of trade and horizontal MP with firm heterogeneity and market access frictions. There are two countries denoted by Home and Foreign. Within each country and each period, there are intermediate good producers of unit measure. Infinitely lived representative household chooses how much to consume and work and to save given an array of state contingent internationally traded bonds. Shocks in a particular period t are encapsulated in the term s_t, while the history of shocks until that period are given by the set $s^t = (s_0, s_1, ..., s_t)$.

2.1 Households

I follow the Alessandria and Choi [2007] notation closely and denote variables corresponding to Foreign with an asterisk. Households in Home maximize expected discounted lifetime utility by choosing consumption, labor supply, and bond holdings.

$$U(s_0) = \max_{C(s^t),L(s^t),B(s^t)} \sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi(s^t|s_0) \frac{[C(s^t)^{\gamma}(1-L(s^t))^{1-\gamma}]^{1-\sigma}}{1-\sigma}$$

where β is the discount factor, $\pi(s^t|s_0)$ is the conditional probability of s^t given s_0, $C(s^t)$ is Home consumption, $L(s^t)$ is Home labor supply, and γ and σ are consumption share in composite commodity and the intertemporal elasticity respectively. The intertemporal budget constraint for this Home household is given by,

$$P(s^t)C(s^t) + \sum_{s^{t+1}} Q(s^{s+1}|s^t)B(s^{t+1}) = P(s^t)W(s^t)L(s^t) + B(s^t) + \Pi(s^t)$$

where $P(s^t)$ is the price of aggregate final good, $Q(s^{t+1})$ is the price of state-contingent bond $B(s^{t+1})$ at time t, $W(s^t)$ is the real wage, and $\Pi(s^t)$ is the total profits of intermediate good producers owned by Home households. The Foreign utility function and the budget constraint are defined similarly using $e(s^t)$ as the nominal exchange rate between the two countries. The Foreign household's budget constraint is,

$$P^*(s^t)C^*(s^t) + \sum_{s^{t+1}} \frac{Q(s^{s+1}|s^t)}{e(s^t)} B^*(s^{t+1}) = P^*(s^t)W^*(s^t)L^*(s^t) + \frac{B^*(s^t)}{e(s^t)} + \Pi^*(s^t)$$

The first-order conditions for the Home household are,

$$\frac{U_L(s^t)}{U_C(s^t)} = W(s^t) \tag{1}$$

$$Q(s^{t+1}|s^t) = \beta\pi(s^{t+1}|s^t)\frac{U_C(s^{t+1})}{U_C(s^t)}\frac{P(s^t)}{P(s^{t+1})} \tag{2}$$

where $W(s^t)$ is the real wage rate in Home and $Q(s^{t+1}|s^t)$ is the stochastic discount factor.

2.2 Final good producer

The Home final good producer combines all the varieties available in Home. The production function is given by,

$$D(s^t) = \left[\delta_h \left[\int_{i=0}^{1} y_h(i,s^t)^\theta di\right]^{\frac{\rho}{\theta}} + \delta_x \left[\int_{\xi^{X*}(s^t)} y_{xf}(i,s^t)^\theta di\right]^{\frac{\rho}{\theta}} + \right.$$
$$\left. (1-\delta_h-\delta_x)\left[\int_{\xi^{M*}(s^t)} y_{mf}(i,s^t)^\theta di\right]^{\frac{\rho}{\theta}}\right]^{\frac{1}{\rho}}$$

where $D(s^t)$ the output of the final good, $y_h(i,s^t)$ is the intermediate Home variety sold domestically, $y_{xf}(i,s^t)$ is the intermediate variety exported from Foreign, and $y_{mf}(i,s^t)$ is the intermediate from Foreign multinationals produced at Home; δ_h and δ_x are home bias and import share parameters; $\xi^{X*}(s^t)$ and $\xi^{M*}(s^t)$ are respectively the set of varieties exported and served by multinationals from Foreign. Note that both $\xi^{X*}(s^t)$ and $\xi^{F*}(s^t)$ are sets of Foreign varieties sold in Home, but the production location is different for the two sets. Given the production function above, the elasticity of substitution between two varieties from the same country is $\frac{1}{1-\theta}$; the elasticity between varieties from different countries is $\frac{1}{1-\rho}$.

Let $P_h(i,s^t)$, $P_h(s^t)$, $P_{xf}(s^t)$, and $P_{mf}(s^t)$ be the Home price of a Home-produced variety i, the aggregate price these varieties, the aggregate price of Foreign exported varieties sold in Home, and the aggregate price of Foreign multinational varieties sold in Home respectively.[5] Then the demand for a given variety from the Home final good producer is,

$$y_h(i,s^t) = \delta_h^{\frac{1}{1-\rho}} \left[\frac{P_h(i,s^t)}{P(s^t)}\right]^{\frac{1}{\theta-1}} \left[\frac{P_h(s^t)}{P(s^t)}\right]^{\mu} D(s^t) \tag{3}$$

$$y_{xf}(i,s^t) = \delta_x^{\frac{1}{1-\rho}} \left[\frac{P_{xf}(i,s^t)}{P(s^t)}\right]^{\frac{1}{\theta-1}} \left[\frac{P_{xf}(s^t)}{P(s^t)}\right]^{\mu} D(s^t) \tag{4}$$

$$y_{mf}(i,s^t) = (1-\delta_h-\delta_x)^{\frac{1}{1-\rho}} \left[\frac{P_{mf}(i,s^t)}{P(s^t)}\right]^{\frac{1}{\theta-1}} \left[\frac{P_{mf}(s^t)}{P(s^t)}\right]^{\mu} D(s^t) \tag{5}$$

where $\mu = 1/(1-\theta) - 1/(1-\rho)$ is the difference in elasticities between domestic and foreign aggregates. Since exporting involves an iceberg cost, an exporter's price is higher compared to the case when it were to set up an affiliate. Given everything else, this implies that a firm faces higher demand if it were to conduct MP. Finally, the aggregate

[5] $P_h(s^t) = \left[\int_0^1 P_h(i,s^t)^{\frac{\theta}{\theta-1}} di\right]^{\frac{\theta-1}{\theta}}$, $P_{xf}(s^t) = \left[\int_{\xi^{X*}(s^t)} P_{xf}(i,s^t)^{\frac{\theta}{\theta-1}} di\right]^{\frac{\theta-1}{\theta}}$, $P_{mf}(s^t) = \left[\int_{\xi^{M*}(s^t)} P_{mf}(i,s^t)^{\frac{\theta}{\theta-1}} di\right]^{\frac{\theta-1}{\theta}}$

price in Home is a combination of domestic, imported, and foreign affiliate prices,

$$P(s^t) = \left[\delta_h^{\frac{1}{1-\rho}} P_h(s^t)^{\frac{\rho}{\rho-1}} + \delta_x^{\frac{1}{1-\rho}} P_{xf}(s^t)^{\frac{\rho}{\rho-1}} + (1-\delta_h-\delta_x)^{\frac{1}{1-\rho}} P_{mf}(s^t)^{\frac{\rho}{\rho-1}}\right]^{\frac{\rho-1}{\rho}} \tag{6}$$

2.3 Intermediate producers

2.3.1 Production function

The production function for the intermediate varieties at any given location is a Cobb-Douglas combination of appropriate capital & labor inputs, and a TFP,

$$y^a(i,s^t) = A^a(i,s^t) K^a(i,s^t)^{\alpha} L^a(i,s^t)^{1-\alpha}$$

where $y^a(i,s^t)$ is the total output in mode $a \in \{domestic(D), export(X), MP(F)\}$, for firm i with capital $K^a(i,s^t)$ and labor $L^a(i,s^t)$.

Production then must occur subject to the following capital constraint:

$$K^D(i,s^t) + K^X(i,s^t) + K^F(i,s^t) \leq K(i,s^{t-1}) \tag{7}$$

The objects on the left hand side of the above equation are denoted in the current time, while the right hand side is in the last-period. This is simply to emphasize the fact that a firm can choose today the capital it allocates to different activities (objects in the lhs), but the capital stock itself was carried over from the previous period (the rhs).

The interaction of firm-owned capital and multinational production generates interesting features that are the focus of this paper. Equation 7 assumes that capital market must clear within each firm: if a firm then decides to be a multinational, its capital must come from its parent entity and the sum of the parent's and affiliate's capital must in equilibrium equal the total capital a firm is born with. If, on the other hand, a firm decides not to conduct MP, its problem is identical to that in firm-owned capital models without MP, such as Alessandria and Choi [2007]. This way of modelling firm owned capital and MP mimics the idea that multinationals have internal capital markets, which I extend to a business cycle context.[6,7]

[6]Existing corporate finance literature points to two reasons why internal capital markets are optimal for multinational firms: i. to move investments from lagging production units to more productive ones, i.e, conduct "winner-picking", which improves the global diversification premium they can offer to their investors (Stein [1997], Sturgess [2016]), and ii. to reduce dependence on external financing when financial markets and underdeveloped and institutions are weak.

[7]Alternatively, one can think of the firm capital to be an amalgam of tangible and intangible components and technology capital. Helpman [1984], for example, models these components explicitly, where the main feature is that technology capital is firm specific but can be used in multiple locations. While I do not model technology capital and its accumulation, thinking of firm capital as an amalgamation of tangible and intangible sub-components helps in rationalising how capital moves across countries at business cycle frequencies in the model.

The MP technology transfer is a combination of Cravino and Levchenko [2017], Zlate [2016], and Contessi [2010]. Cravino and Levchenko [2017] model affiliate productivity as a combination of aggregate and idiosyncratic components of parent and affiliate entities. For computational simplicity, I assume that idiosyncratic productivity is transferred fully across borders as in Zlate [2016] and Contessi [2010]. The productivity term $A_{jk}(i, s^t)$, where j is the source country and k is the destination, therefore involves home and host aggregate and idiosyncratic components,

$$A_{jk}(i, s^t) = \exp\left(\zeta Z_j(s^t) + (1-\zeta)Z_k(s^t) + \eta(i, s^t)\right) \tag{8}$$

where $Z_j(s^t)$ and $Z_k(s^t)$ are home- and destination-specific aggregate productivities respectively, $\eta(i, s^t)$ is the firm's idiosyncratic productivity, and ζ is the technology share parameter such that a fraction ζ of parents' productivity spills over to the affiliates. Referring to the notation above, productivity by activities $A^D(i, s^t)$ and $A^X(i, s^t)$ are obtained by setting $j = k$, while the MP affiliate productivity $A^F(i, s^t)$ is obtained by plugging in appropriate values for j and k.

The aggregate productivities follow a vector auto-regressive process. In the matrix form,

$$Z(s^t) = MZ(s^{t-1}) + \nu(s^t), \quad \nu(s^t) \overset{i.i.d.}{\sim} N(0, \Omega)$$

Where M is the matrix of AR1 parameters, and ν is the innovation to aggregate productivity, assumed to be i.i.d. across countries and over time. The firm specific productivity, η, is also distributed i.i.d. across firms and over time $\eta \overset{i.i.d.}{\sim} N(0, \sigma_\eta^2)$.

2.3.2 Costs

Because there are no additional frictions to serve the domestic market, all intermediate firms choose to serve domestically. However, firms face frictions if they wish to serve the foreign market. If a firm chooses to export, it pays an exporting fixed cost F^X/ϕ where $\phi = 1$ for non-MP firms in $t-1$ and $\phi > 1$ for MP firms in $t-1$. This implies that MP firms have an advantage in exporting subsequently and captures the idea that MP firms have already established international supply chain networks which allows them to export more cheaply.[8]

On the other hand, if a firm chooses to setup an affiliate abroad and serve the foreign market by producing locally, it pays a (larger) fixed cost F_1^F. In addition, a new affiliate (i.e., a firm which did not have affiliates last period) pays a sunk cost F_0^F. I assume that

[8] I use ϕ to set the relative slopes of export and MP value functions for current MP firms. When $\phi = 1$ for all firms so that export fixed cost is the same for both MP and non-MP firms, MP value function intercept is lower than export value functions, but the MP value function is much steeper. As a result, the MP exit cutoff is lower than the export entry cutoff meaning that MP firms never exit to become exporters. Higher ϕ steepens the export value function and fixes the relative values of productivity thresholds in the expected pattern.

both the fixed costs and the MP sunk cost are paid in labor units in the market being served.

2.3.3 Firm value

Total value of a firm i originating in Home is the sum of its discounted expected profits across all activities. For a given period, firms' state variables are: 1. Idiosyncratic productivity (η), 2. Capital stock of the firm, 3. MP choice last period, and 4. The aggregate macroeconomic conditions. Firms choose the markets to serve, the mode of serving the foreign market conditional on the foreign market being served, optimal allocation of capital across production units, quantity sold in each market, and the level of investment. In the recursive form, firms' problem can be written as,

$$\begin{aligned} V(\eta, K, m^F, s^t) = \max \Pi^D(i, s^t) + m^{X'}(i, s^t)\Pi^X(i, s^t) + m^{F'}(i, s^t)\Pi^F(i, s^t) \\ - P(s^t)x(i, s^t) + \sum_{s^{t+1}} \sum_{\eta'} Q(s^{t+1}|s^t)Pr(\eta')V(\eta', K', m^{F'}, s^{t+1}) \end{aligned} \quad (9)$$

where η is firm's idiosyncratic productivity, $m^{X'}(i, s^t)$ and $m^{F'}(i, s^t)$ are indicators that equal 1 if a firm i exports or conducts MP in the current period, $x(i, s^t)$ denotes investment. For every firm, the capital accumulation equation is satisfied, and the capital equilibrium condition holds:

$$(1 - \delta_k)K(i, s^{t-1}) + x(i, s^t) = K(i, s^t) \quad (10)$$

$$K^D(i, s^t) + m^{X'}(i, s^t)K^X(i, s^t) + m^{F'}(i, s^t)K^F(i, s^t) = K(i, s^{t-1}) \quad (11)$$

The domestic, export, and MP profits, in terms of the Home currency are,

$$\Pi^D(i, s^t) = P_h(i, s^t)y^D(i, s^t) - P(s^t)W(s^t)L^D(i, s^t) \quad (12)$$

$$\Pi^X(i, s^t) = e(s^t)P_h^{X\star}(i, s^t)y^X(i, s^t) - P(s^t)W(s^t)L^X(i, s^t) - e(s^t)P^\star(s^t)W^\star(s^t)\frac{F^X}{\phi} \quad (13)$$

$$\begin{aligned} \Pi^F(i, s^t) = e(s^t)\Big[P_h^{F\star}(i, s^t)y^F(i, s^t) - \\ P^*(s^t)W^*(s^t)\left\{L^F(i, s^t) + F_1^F + (1 - m^F(i, s^t))F_0^F\right\}\Big] \end{aligned} \quad (14)$$

2.3.4 Productivity cutoffs and choices

Every firm produces in the domestic market, but the set of exporters and affiliates is endogenous. I denote $\eta_0^X(s^t)$, $\eta_1^X(s^t)$, $\eta_0^F(s^t)$, and $\eta_1^F(s^t)$ as the export and MP productivity thresholds among last-period non-MP and MP firms respectively. I denote by $V^D(i, s^t)$,

$V^X(i,s^t)$, and $V^F(i,s^t)$ the values of a given firm i given its state variables by choosing to serve only the domestic market, being exporter, and conducting MP respectively. Formally, I define the marginal exporter, given MP status last-period, as the firm for which the following holds:

$$V^D(\eta^X_{m^F}, K, m^F, s^t) = V^X(\eta^X_{m^F}, K, m^F, s^t) \tag{15}$$

And for the marginal MP firm, given MP status last period,

$$V^X(\eta^F_{m^F}, K, m^F, s^t) = V^F(\eta^F_{m^F}, K, m^F, s^t) \tag{16}$$

2.3.5 Aggregation

Given the cutoffs, the laws of motion for number of exporters and MP firms originating in each country, $N^X(s^t)$ and $N^F(s^t)$, can be written as,

$$N^F(s^t) = [1-\Phi(\eta^F_1(s^t))]N^F(s^{t-1}) + [1-\Phi(\eta^F_0(s^t))][1-N^F(s^{t-1})]$$

$$N^X(s^t) = \left[\Phi(\eta^F_1(s^t)) - \Phi(\eta^X_1(s^t))\right] N^F(s^{t-1}) + \left[\Phi(\eta^F_0(s^t)) - \Phi(\eta^X_0(s^t))\right] \left[1-N^F(s^{t-1})\right]$$

where $\Phi(\cdot)$ is the cumulative density function of η. Because the firms' idiosyncratic distribution is assumed to be i.i.d., firms' expectation of the future profits are entirely determined by their MP status in the current period. Consequently, every firm that conducts MP today expects the same profit tomorrow, and decides on the same level of capital stock for tomorrow (denoted $K_1(s^t)$); every current non-MP firm also has the same level of capital stock (denoted $K_0(s^t)$). The aggregate capital stock and investment can then be written as,

$$K(s^t) = \left[1-N(s^t)\right] K_0(s^t) + N(s^t)K_1(s^t)$$

$$X(s^t) = K(s^t) - (1-\delta_k)K(s^{t-1})$$

The aggregates for labor demand, price indexes, and profits are derived in the appendix.

2.4 Equilibrium

The equilibrium in the economy is a set of quantities of labor $\{L(s^t), L^\star(s^t)\}$; consumption $\{C(s^t), C^\star(s^t)\}$; bond holdings $\{B(s^t), B^\star(s^t)\}$; investment $\{X(s^t), X^\star(s^t)\}$; output $\{D(s^t), D^\star(s^t)\}$, capital choices $\{K_0(s^t), K^\star_0(s^t), K_1(s^t), K^\star_1(s^t)\}$, number of exporters and affiliates $\{N^X(s^t), N^{X\star}(s^t), N^F(s^t), N^{F\star}(s^t)\}$, aggregate profits $\{\Pi(s^t), \Pi^\star(s^t)\}$, and prices $\{q(s^t), P_h(s^t), P_f(s^t), P^\star_h(s^t), P^\star_f(s^t), P(s^t), P^\star(s^t), W(s^t), W^\star(s^t)\}$ such that in each country and in each period,

1. Households bond holdings first order condition (FOC) and labor supply FOC are satisfied

2. Households' budget constraints are satisfied

3. Firms' investment FOC holds

4. International bond market is in equilibrium

5. Labor markets are in equilibrium

6. All intermediate goods markets, and the final good markets are in equilibrium

7. Marginal exporters and MP firms' conditions are satisfied

Mathematical derivations for the model equations are in Appendix A.

3 Calibration

The model is calibrated to mimic key features of MP in the United States at quarterly frequency. I focus on MP firms' size and their transition rates. A list of the twenty one model parameters and their values under the benchmark calibration are given in Table 1.

I set fourteen parameters based on their values in existing literature. Among the demand side parameters, I set β equal to $\frac{1}{1+r/4}$ so that the annual real return $r = 4\%$. Consumption share in composite commodity, γ equals 0.303 and intertemporal elasticity equals two as in Alessandria and Choi [2007]. Capital share and the depreciation rate for capital is standard across growth and business cycle literature: $\alpha = 0.36$ and $\delta_k = 0.025$. Domestic and international elasticity parameters, θ and ρ, are set to 0.8 and 0.33. Own and cross aggregate shock persistence parameters are 0.95 and zero respectively; and the standard errors of the innovation to aggregate shocks are set to 0.007, all following Alessandria and Choi [2007]. For the technology transfer parameter, ζ, there is no precedence in the literature. Cravino and Levchenko [2017] estimate it to be between 20-40%, but their model does not map one-to-one with the model in this paper. In the baseline, I assume that $\zeta = 30\%$ and compare the results with technology transfer shut down ($\zeta = 0$). The focus of this experiment is to understand how technology transfer impacts business cycle dynamics.

The parameter ϕ helps in matching the MP firms' transition rates to the data. I set it to 30 under benchmark calibration, meaning that the export fixed cost for last period MP firms is 30 times lower than last period non-MP firms. The results are not sensitive to the exact value of ϕ as I show with robustness checks in column 8 of Table 3 as long as the MP transition rates match the data.

Table 1: Benchmark Parameter Values

Parameter	Description	Value	
	Parameters		Source
β	Time preference	0.99	Annual return = 4%
γ	Share of consumption	0.303	C/Y in steady state = 78%
σ	Inter-temporal elasticity	2	$\in [1, 5]^*$
α	Capital share	0.36	$\in [0.35, 0.4]^*$
ζ	MP technology transfer	30%	Assumed
θ	Domestic elasticity	0.8	$\in [0.7, 0.9]^*$
ρ	International elasticity	1/3	Alessandria and Choi [2007]
δ_k	Depreciation rate	0.025	$\in [0.02, 0.04]^*$
ϕ	MP export advantage	30	Assumed
M_{11}, M_{22}	Own persistence	0.95	Alessandria and Choi [2007]
M_{12}, M_{21}	Cross persistence	0	Alessandria and Choi [2007]
Ω_{12}, Ω_{21}	SE, aggregate shock	0.007	Alessandria and Choi [2007]
	Calibrated		Targets
δ_h	Home preference	0.59	MP entry rate = 0.074%
δ_x	Import preference	0.21	MP exit rate = 0.59%
F^X	Export fixed cost	0.03	MP empl. share = 26%
F_0^F	MP sunk cost	0.82	Exporters = 21%
F_1^F	MP fixed cost	0.07	Import share = 15.2%
σ_η	SE, idiosyncratic shock	0.67	Exporter premium = 12-18%

*: literature uses values within these bounds, and the parameter is calibrated to the most commonly used value in the range.
Target moments are from Boehm et al. [2020] and Bernard and Jensen [1999].

The six remaining parameters are calibrated to jointly match six moments in the data. In particular, I target: i. MP entry rate equal to 0.0738%, ii. MP exit rate equal to 0.5919%, iii. MP employment share equal to 26%, iv. number of exporters equal to 21% of all firms, v. exporter productivity premium relative to domestic firms equal to 15%, and vi. import to GDP ratio equal to 15%. The MP entry and exit rates are from Boehm et al. [2020].[9] MP employment share is from Antras and Yeaple [2014]. Number of exporters and exporter productivity premium is from Bernard and Jensen [1999]. Imports to GDP ratio is from post-war US data until 2016. Table 2 shows that the model mimics key moments in the data – it matches the MP firm transition rates exactly, the import share is only slightly below the target, and exporter productivity is within the observed range. The MP employment share is well below the target, meaning that the calibration gives less importance to MP than in the data. The results then need

[9] I describe my calculations in Appendix B. Boehm et al. [2020] report average annual transition probabilities for US firms and foreign multinationals operating in the US calculated over 1993-2011. I account for exit while calculating the transition probabilities.

Table 2: Calibration - Model and the Data

Moment	Target	Model
MP entry rate	0.074%	0.074%
MP exit rate	0.59%	0.59%
MP employment share	26%	20.26%
No. exporters	21.28%	20.96%
Import share	15.05%	14.86%
Exporter productivity premium	[1.12,1.18]	1.14

to be interpreted as a lower bound on the importance of MP.

4 Results

In this section, I discuss the results from the quantitative exercises. I begin by discussing how macro moments change when MP is allowed and then discuss the mechanisms. Table 3 lists these moments under various model scenarios and lists the data values of these moments. The numbers reported in Table 3 are averages across 1000 simulations where each variable is HP filtered with a smoothing parameter of 1600. Figures 1 and 2 provide relevant impulse responses.

Aggregate variables. Columns 2 and 3 of Table 3 list the values of aggregate international business cycle moments under the benchmark MP calibration and the no-MP model. For the no-MP model, I simulate Alessandria and Choi [2007] under their benchmark calibration.[10] Data values for the US (taken from Kehoe and Perri [2002]) are in column 1. I focus on business cycle moments related to output, consumption, investment, employment, net exports, and real exchange rate. For these variables, I report their standard deviations, correlations with output, persistence, and international correlations where appropriate.

Volatility. I begin by noting that the standard deviations of nearly all the variables are higher in the benchmark MP calibration than in the no-MP model. The volatility of output is higher in the MP model by 11 percentage points while that of net exports to output ratio is higher by 3 percentage points. In the case of output, the distance to data in the MP model is lower by 21% and it is lower by 10% in the case of net exports to output ratio. The model brings these two volatilities closest to the data in percentage terms. Standard deviations of employment and real exchange rate are also closer to the data but by a smaller 2.6% and 0.4% respectively. Consumption is not more volatile in the model compared to the no-MP case, but investment is considerably more volatile and not in accordance with the US data. There is higher volatility in the MP model

[10] Alessandria and Choi [2007] simulate an international business cycle model with only export and no MP.

Table 3: Comparison of Business Cycle Statistics

	Data	Benchmark	No MP	Change, Distance to Data (%)	No Tech. Transfer	Fixed Exit MP	Fixed Exit Trade	High ϕ ($\phi = 40$)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Standard deviation (in percent)								
Y	1.72	1.38	1.29	-20.93	1.44	1.35	1.36	1.38
nx	0.46	0.2	0.17	-10.34	0.21	0.19	0.17	0.2
Standard deviation (relative to output)								
C	0.79	0.36	0.36	0.00	0.36	0.36	0.36	0.36
X	3.25	3.81	3.4	273.33	3.82	3.8	3.71	3.81
L	0.85	0.47	0.46	-2.56	0.47	0.47	0.46	0.47
q	2.81	0.34	0.33	-0.40	0.37	0.33	0.33	0.33
Domestic Correlations with Output								
C	0.83	0.95	0.95	0.00	0.95	0.95	0.95	0.95
X	0.93	0.97	0.98	-20.00	0.97	0.97	0.98	0.97
L	0.85	0.98	0.99	-7.14	0.98	0.98	0.99	0.98
nx	-0.38	-0.55	-0.51	30.77	-0.57	-0.53	-0.56	-0.55
q	0.16	0.63	0.58	11.90	0.67	0.61	0.62	0.62
q,nx	0.07	-0.56	-0.51	8.62	-0.58	-0.54	-0.55	-0.56
Persistence								
Y	0.87	0.7	0.69	-5.56	0.7	0.69	0.7	0.7
C	0.91	0.73	0.73	0.00	0.73	0.72	0.73	0.73
X	0.84	0.69	0.68	-6.25	0.7	0.68	0.69	0.69
L	0.95	0.69	0.68	-3.70	0.7	0.68	0.69	0.69
nx	0.9	0.74	0.71	-15.79	0.75	0.72	0.74	0.74
q	0.81	0.77	0.79	100.00	0.77	0.77	0.77	0.77
International Correlations								
Y	0.51	0.08	0.2	38.71	-0.01	0.11	0.08	0.09
C	0.32	0.51	0.53	-9.52	0.41	0.53	0.52	0.52
X	0.29	-0.19	-0.03	50.00	-0.27	-0.16	-0.14	-0.19
L	0.43	-0.02	0.19	87.50	-0.1	0.02	0.01	-0.01

A comparison of important business cycle statistics under different model parameterizations. The first column contains these moments for the United States, taken from Kehoe and Perri [2002]. Change in distance to data (column 4) is computed as the difference in distance between the benchmark and the data and the no-MP model and the data as a percentage of the distance between no-MP model and the data. A negative change in distance represents an improvement of the benchmark model over the no-MP model.

because of MP extensive margin – as MP firms are allowed to enter and exit, there is greater volatility of capital stock and the number of firms; because MP firms are large, they generate large fluctuations in aggregate variables. I discuss the mechanisms in more detail in Section 4.1.

Domestic correlations. Among the domestic correlations, the MP model improves on the no-MP model in the cases of investment and employment. The investment-output correlation in the MP model is lower by 1 percentage point. While this may appear to be a small change, it is 20% closer to the US data. For employment-output correlation too, the MP model is closer to data by 1 percentage point, which brings it closer to the data by 7%. There is no change in consumption-output correlation in the MP model. Net exports is more negatively correlated with output while real exchange rate is more positively correlated, and these moments are farther from the US data compared to the

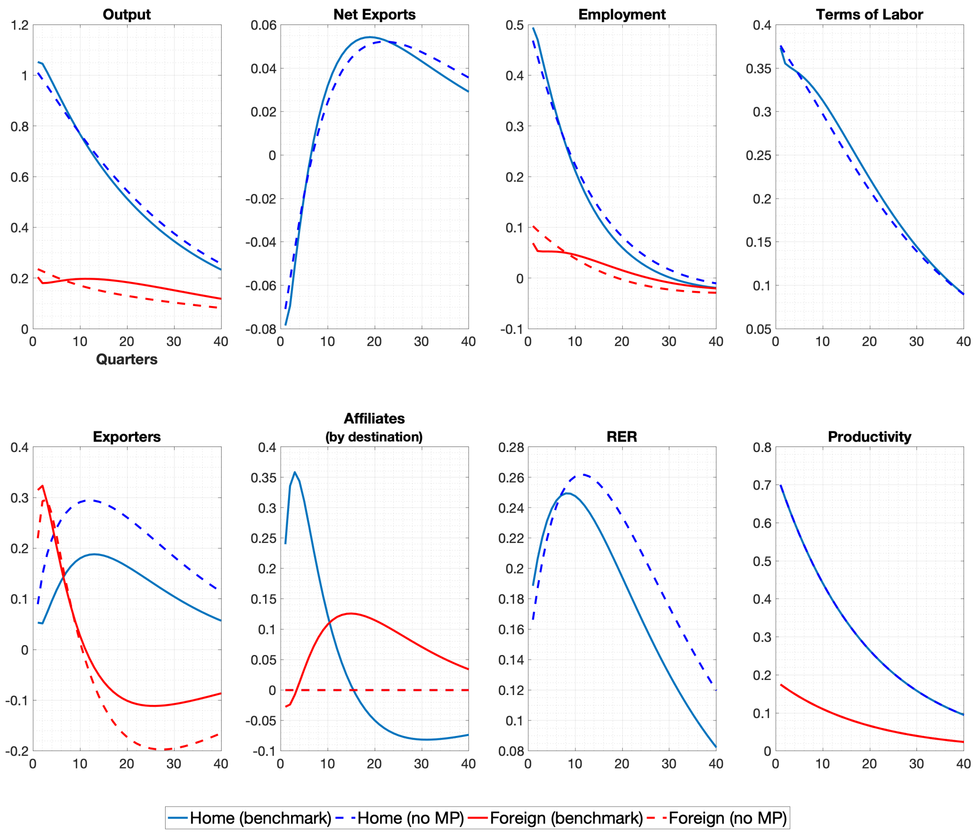

Figure 1: Impulse Responses for the MP and No-MP Models

no-MP model. The net-exports and output correlation too is more negative in the MP model and is farther from the US data.

Persistence. The MP model matches the persistence of output, investment, employment, and net exports better. Among these, the persistence of output, investment, and employment are all higher by 1 percentage point and closer to the data by over 5.5%, 6.3%, and 3.7% respectively. Persistence of net exports improves the most in percentage terms (15.8% and 3 percentage points). Persistence of consumption is unchanged while that of real exchange rate increases by 2 percentage points not in accordance with the data (farther away from data by 100%).

International correlations. Finally, I report the international correlations of output, consumption, investment, and employment. Correlations of all of these variables are lower in the MP model. In the case of consumption, however, the fall in correlation makes the model more in line with the data. In particular, the distance between model and data is lower by 9.5% for consumption in the MP model. However, the fall in correlations of output, investment, and employment makes the model less aligned with the data.

To summarise, the model generates values closer to the data for eleven of the 22 moments considered in Table 3. For six of these moments (volatilities of output and net exports, international consumption correlation, persistence of net exports, and employment-

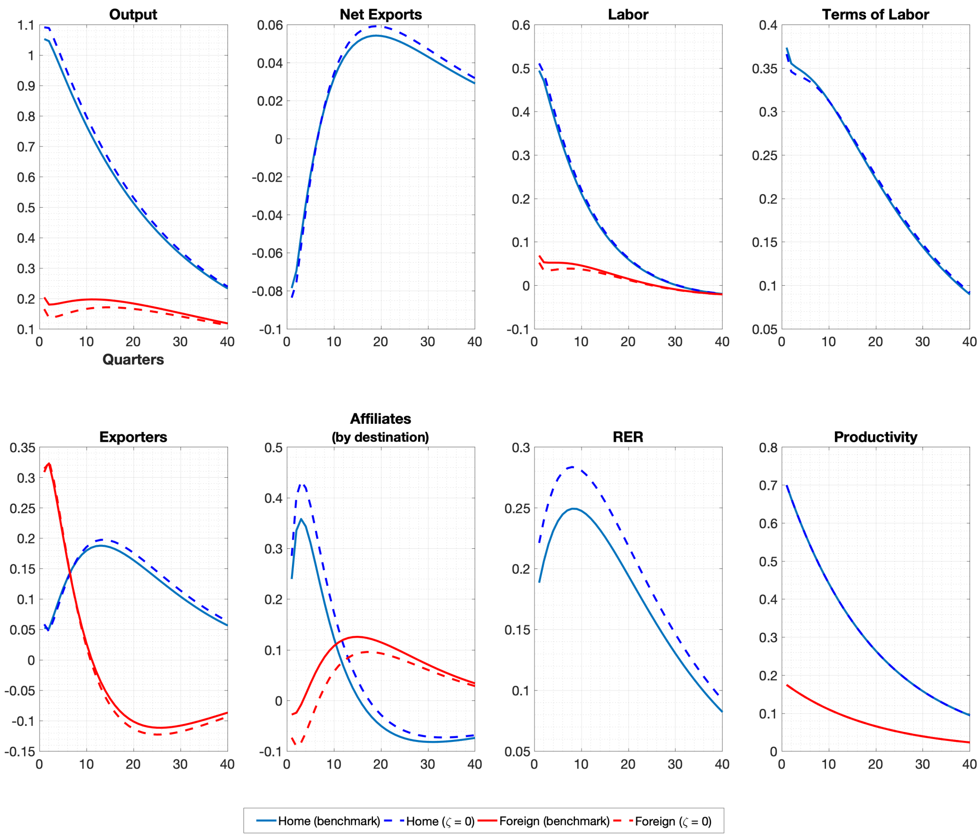

Figure 2: Impulse responses with Different Technology Transfer Levels

output and investment-output correlations), the MP model generates over seven percent improvement. Among the eleven remaining moments, there is no change compared to the no-MP model for three moments while the MP model is farther from the data for eight moments. Of greatest concern (in terms of percentage deviation from data) are the volatility of investment, persistence of real exchange rate, and international investment and employment correlations which deviate by more than 50% compared to the no-MP model.

In what follows, I explain the main mechanisms that generate differences between the MP and no-MP models.

4.1 The Role of Technology and Resource Transfers

There are three channels in the benchmark model that affect IRBC dynamics. First, there is an inflow of MP firms into the country that experiences an aggregate technology improvement (Home). There is an increase in Foreign firms' affiliates and a drop in Home firms' affiliates abroad. As these firms bring in capital, there is an inflow of physical capital to Home. This is the novel "resource transfer" channel via multinationals. Home output expands both because there is greater economic activity with more resources (i.e., capital) and because of the greater number of varieties being produced. Under the benchmark calibration, there is a small decrease in the mass of Home owned affiliates in Foreign, and a bigger 0.25% increase in the mass of Foreign owned affiliates in Home. The no-MP economy, by definition, does not generate any variation in the number of affiliates, so the dashed impulse response lines in sub-figure 6 Figure 1 is flat at zero.

The increase (decrease) in Foreign (Home) affiliates in Home (Foreign) is driven by both static and dynamic factors. The Foreign firms pay higher fixed cost compared to export fixed cost (and new affiliates pay sunk cost in addition to that), but they are compensated for by higher operational profits due to more favorable terms of labor in Home. To show this more clearly, I plot Home terms of labor defined as the effective wage rate in Foreign relative to Home. An increase (interpreted as a depreciation) implies an increase in the relative cost of producing in Foreign. It captures the wage differential as experienced by a Foreign firm contemplating between exporting from Foreign versus conducting MP:

$$ToL = \frac{q(s^t)W^\star(s^t)}{Z^\star(s^t)} \times \frac{Z(s^t)}{W(s^t)}$$

Sub-figure 4 of Figure 1 shows Home terms of labor to improve by nearly 0.4% upon impact. This discourages firms from producing abroad to sell in Home. As a result, fewer Home multinationals want to continue operating affiliates abroad and more Foreign firms want to set up affiliates in Home. In addition to improving the static profits, new Foreign multinationals see a benefit in incurring the MP sunk cost when it is cheaper to do so. The associated fall in MP entry and exit cutoffs in Foreign increase the chances of staying on as a multinational in the future, so the value of conducting MP increases. Given everything else, this leads to greater increase in Home output and a smaller increase in Foreign output, resulting in lower output comovement. In addition, because firms relocate, the volatilities of macro variables are higher.

MP resource transfer versus technology transfer: The impact of the two channels can be summarized as follows. Compared to the no-MP model, the resource transfer channel via MP makes macro variables less correlated across countries and more volatile; the technology transfer channel dampens the resource transfer channel. Referring to the Home aggregate shock above, on the one hand, exporting (MP) is more attractive for Home (Foreign) firms relative to MP (exporting) as Home effective wage rate falls. On the other hand, technology transfer makes MP (exporting) more attractive as Home (Foreign) firms can carry their productivity advantage (disadvantage) abroad. The impact on the number of MP firms is a result of these two opposite forces. In the net in the calibrated model, technology transfer channel is not powerful enough to overcome the cheaper production cost in Home. In a business cycle sense, there is greater volatility in the number of firms and capital stock in each country which translates to greater macroeconomic volatility.

Second, like in the trade models, entry and exit of exporters contributes to comovement (solid lines in sub-figure 5, Figure 1) but this channel is weaker in the MP model. To export or not is a static decision. The number of Home exporters increases because cheaper production costs increase their profits abroad. Consequently, high productivity non-exporter and non-MP firms that previously could not cover the export fixed cost can do so when profits are higher. Foreign firms on the other hand benefit from an increased demand from Home which sufficiently counteracts their productivity deficit. In Home, the MP entry and export cutoffs rise, which increases the mass of exporters. In Foreign, MP entry and exit cutoffs fall, but export entry cutoff falls sufficiently to raise the overall number of exporters. The increase in mass of Home exporters means that the foreign final good producer has more varieties to choose from. As shown in Liao and Santacreu [2015], this "variety-effect" is quantitatively important and contributes to an increase in Foreign output. The no-MP model generates qualitatively the same dynamics of the mass of exporting firms as in the benchmark case. Both Home and Foreign see an increase in exporters.

Third, international risk sharing with complete markets results in the standard resource transfer towards Home. This channel, where relatively higher investment in Home leads to divergent paths for capital, is present in early quantitative trade models with a single producer (for example, Backus et al. [1994], as noted in Kose and Yi [2006]). The differences in investments is driven by a persistent Home productivity shock that promises higher returns into the future. This leads to Home accumulating a bigger stock of capital than Foreign, so the two countries output comove negatively as a result.

The resource transfer channel via multinationals, a new channel in this paper, therefore differs from those in trade models where households own capital stock (Kose and Yi [2006]). The mechanism in trade-only models is gradual and is a result of household investment decisions: Home households borrow internationally to invest more while the Foreign households lower their investments, and the two countries' stock of capital diverge over time. This too reduces output comovement, as shown by Kose and Yi [2006]. In the MP model in this paper, the traditional resource transfer channel is further strengthened by multinationals as transfer of capital stock towards Home is instantaneous. The immediate relocation of capital adds to macroeconomic volatility.

5 Conclusions

Even though multinational activity (primarily of horizontal type) has seen a dramatic rise since 1990, much more so than trade during the same time, international business cycle research has largely ignored multinational production as a spillover channel. I develop a quantitative model of MP and trade with firm heterogeneity, technology transfer via

MP firms, physical capital, market access frictions including a sunk cost of MP. I use this model to test how MP affects business cycle dynamics.

The main finding from model simulations is that MP firms' entry and exit has a quantitatively important impact on business cycle variables. In particular, MP increases macroeconomic volatility, reduces persistence, and reduces international correlations of output, consumption, investment, and employment. For eleven of the 22 macroeconomic moments tracked, the MP model is closer to the data compared to a trade model. The model gets closest to the data (in percentage terms) for output and net exports volatilities, investment-output correlation, and international consumption correlation. For eight of the remaining eleven moments the model is farther from the data compared to the trade model.

I explain these findings, in particular the increase in macro volatility and the fall in international correlations, with two competing channels at play in the MP model: technology and resource transfer. A country experiencing productivity increase attracts more foreign firms and more home exporters, leading to a relocation of capital towards that country. This channel is driven by cheaper labor in the higher productivity country. Technology transfer reduces incentive to shift towards the higher productivity country, thus counteracting the resource transfer channel. In the net, however, the technology transfer channel is not powerful enough to overcome the resource transfer channel.

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A Technical Appendix

Firm prices: Given the monopolistic competitive market structure, an intermediate producer's price in different markets, conditional on the mode of serving those markets, is a constant markup ($= 1/\theta$) above the marginal cost of production:

$$\frac{P_h(i,s^t)}{P(s^t)} = \frac{W(s^t)}{\theta F_l^D(i,s^t)} \tag{17}$$

$$\frac{P^\star_{xf}(i,s^t)}{P^\star(s^t)} = \frac{P_h(i,s^t)}{P(s^t)}\frac{\tau}{q(s^t)} \tag{18}$$

$$\frac{P^\star_{mf}(i,s^t)}{P^\star(s^t)} = \frac{W^\star(s^t)}{\theta F_l^M(i,s^t)} \tag{19}$$

$F_l^D(i,s^t)$, and $F_l^M(i,s^t)$ are marginal labor productivities in the domestic and the foreign plant, $P^\star_{xf}(i,s^t)$ and $P^\star_{mf}(i,s^t)$ are the prices charged by the Home firm i if it exported or if it conducted MP respectively.[11]

Labor demands: Because capital is fixed, firms can only adjust the labor in their production function to meet the demand for their variety. For a current non-multinational ($m^{M'}(i,s^t) = 0$), the total labor demand can then be derived by equating the firm output to the demand it faces: $A_{hh}(i,s^t)K(i,s^{t-1})^\alpha L(i,s^t)^{1-\alpha} = y_h(i,s^t) + m^{X'}(i,s^t)\tau y^\star_{xf}(i,s^t)$. Plugging in demands for variety from 3 and 5 and prices 17 and 18 in the rhs, and collecting labor terms together, I get,

$$L_{m^{F'}=0}(i,s^t) = H_{hx}(s^t) \times A(i,s^t)^{\frac{1-\nu}{\alpha}} K(i,s^{t-1})^{1-\nu} \tag{20}$$

where $\nu = (1-\theta)/[1-\theta(1-\alpha)]$ is a constant, and

$$H_{hx}(s^t) = \left[H_h(s^t)^{1/\nu} + m^{X'}(i,s^t)H^\star_x(s^t)^{1/\nu}\right]^\nu \tag{21}$$

$$H_h(s^t) = \left[\delta^{\frac{1}{1-\rho}}\left(\frac{P_h(s^t)}{P(s^t)}\right)^\mu D(s^t)\right]^\nu \left(\frac{W(s^t)}{\theta(1-\alpha)}\right)^{\frac{\nu}{\theta-1}} \tag{22}$$

$$H^\star_x(s^t) = \left[\delta_x^{\frac{1}{1-\rho}}\left(\frac{\tau^\theta}{q(s^t)}\right)^{\frac{1}{\theta-1}}\left(\frac{P^\star_{xf}(s^t)}{P^\star(s^t)}\right)^\mu D^\star(s^t)\right]^\nu \left(\frac{W(s^t)}{\theta(1-\alpha)}\right)^{\frac{\nu}{\theta-1}} \tag{23}$$

$$H^\star_m(s^t) = \left[(1-\delta_h-\delta_x)^{\frac{1}{1-\rho}}\left(\frac{P^\star_{mf}(s^t)}{P^\star(s^t)}\right)^\mu D^\star(s^t)\right]^\nu \left(\frac{W^\star(s^t)}{\theta(1-\alpha)}\right)^{\frac{\nu}{\theta-1}} \tag{24}$$

are macroeconomic aggregates for Home-owned firms in Home and Foreign respectively. These aggregate do not carry any economic interpretation- they are collections of prices, real wage and the final good output, and come out of the demand functions in 3 and 5 and after collecting the labor terms together.

Next consider a firm that has chosen to be a multinational ($m^{F'}(i,s^t) = 1$). Because it operates in both the countries, I have to specify separately the labor demands in each country. Moreover, the firm can reallocate its capital across the two production locations. Capital allocation affects labor productivities, which impacts the prices charged by the firm and the demand it faces in both the countries. I will take a step back and start by writing labor demands given the capital allocation decision, and then use appropriate first order conditions to find optimal allocations of capital later (see eq. 27 and 29). I will denote by $L^D(i,s^t)$ and $L^{D\star}(i,s^t)$ the labor demands in Home and Foreign for a Home-owned firm. Using the demand for a variety from 3 (given firm's price), and equating it to the production function for MP parents and collecting the labor terms together, I get,

$$L^D_{m^{F'}=1}(i,A^D,K^D) = H_h(s^t)A_{hh}(i,s^t)^{\frac{1-\nu}{\alpha}} K^D(i,s^t)^{1-\nu} \tag{25}$$

[11]It is necessary to distinguish between labor productivities in parent and affiliate entities when conducting MP is a possibility. An MP firm can vary its price by varying these productivities in the two production locations. For example, an MP firm can move capital between the production locations, and thus affect prices in both markets.

is the labor demand in the domestic market given the capital $K^D(i, s^t)$ allocated to that market. Similarly, the conditional labor demand for the affiliate can be derived by equating 5 (using MP price 19) to MP affiliate's production function, and collecting the labor terms together,

$$L^{D\star}_{m^{F'}=1}(i, A_{hf}, K^D) = H^\star_m(s^t) A_{hf}(i, s^t)^{\frac{1-\nu}{\alpha}} (K(i, s^{t-1}) - K^D(i, s^t))^{1-\nu} \tag{26}$$

where $A^D(i, s^t)$ and $A^{D\star}(i, s^t)$ are productivities of the MP parent and affiliate defined in 8.

Next, I solve for the capital allocations of an MP firm across parent and affiliate entities. Allocation of capital affects pricing (by changing the marginal product of labor), and hence the demand that the firm faces in each market. Because capital can be transferred freely across borders, it is allocated to maximize joint profits in each period (i.e., a static decision). Condensing the fixed and sunk costs into a single term, the total static profit of a multinational can be written as,

$$\Pi(total) = \Pi(Parent) + \Pi(Affiliate)$$

$$\begin{aligned}= P_h(i, s^t) y^D(i, s^t) - P(s^t) W(s^t) L^D(i, s^t) \\ + e(s^t) \left[P^{F\star}_h(i, s^t) y^F(i, s^t) - P^\star(s^t) W^\star(s^t) L^{D\star}(i, s^t) \right] - FC\end{aligned}$$

Plug the production functions in 2.3.1, and the capital quantity constraint 7 to get,

$$\begin{aligned}\Pi(total) &= P_h(i, s^t) A^D(i, s^t) K^D(i, s^t)^\alpha L^D(i, s^t)^{1-\alpha} - P(s^t) W(s^t) L^D(i, s^t) + \\ &e(s^t) \Big[P^{F\star}_h(i, s^t) A^{D\star}(i, s^t) \left(\bar{K}(i, s^t) - K^D(i, s^t) \right)^\alpha L^{D\star}(i, s^t)^{1-\alpha} - P^\star(s^t) W^\star(s^t) L^{D\star}(i, s^t) \Big] - FC\end{aligned}$$

$$= \frac{1 - \theta(1-\alpha)}{\theta(1-\alpha)} P(s^t) W(s^t) \left[L^D(i, s^t) + \frac{q(s^t) W^\star(s^t)}{W(s^t)} L^{D\star}(i, s^t) \right] - FC$$

Plugging in the labor demand functions in 25 and 26, and differentiating the above function with respect to domestic capital utilization $K^D(i, s^t)$, it can be written as a function of the capital stock that the firm is born with and macroeconomic aggregates in both the markets,

$$K^D_{m^{F'}=1}(i, s^t) = \frac{K(i, s^{t-1})}{1 + G(s^t)} \tag{27}$$

where

$$G(s^t) = \left(\frac{q(s^t) W^\star(s^t)}{W(s^t)} \frac{H^\star_m(s^t)}{H_h(s^t)} \right)^{1/\nu} h^{(\nu-1)/\nu\alpha} \exp\left(\frac{(1-\nu)(1-\zeta)(Z^\star(s^t) - Z(s^t))}{\nu\alpha} \right) \tag{28}$$

is another macroeconomic aggregate which corresponds to foreign country's relative cost and demand advantage over the home country for MP firms.

The capital stock allocated to the MP firm's affiliate is given by $K^{D\star}_{m^{F'}=1}(i, s^t) = K(i, s^{t-1}) - K^D_{m^{F'}=1}(i, s^t)$, which equals,

$$K^{D\star}_{m^{F'}=1}(i, s^t) = \frac{G(s^t)}{1 + G(s^t)} K(i, s^{t-1}) \tag{29}$$

Clearly, the capital utilization functions 27 and 29 are independent of firms' idiosyncratic productivity. This result simplifies computation greatly, because it implies that every MP firm from Home employs the same fraction of its initial stock in the Home market. When the two countries are identical- i.e., they have the same aggregate states, wages, masses of exporters and MP firms, the MP firms use half of their capital in either location. Whenever one of the countries has lower effective wage, that country receives a greater share of the capital.

Note that the labor demands for MP firms derived in 25 and 26 took the capital allocations as given. So we can plug 27 and 29 back into these functions to get labor demands.

The assumption that firm productivity η is distributed i.i.d greatly simplifies computation. It implies that every firm has the same expectation for η next period. All current MP firms then have the same (and higher) expected value tomorrow on account of having already paid the sunk cost. As a result, these firms choose the same capital stock for tomorrow, denoted $K_1(s^t)$. For the current non-MP firms, the expected value tomorrow is lower, and they invest to have a lower capital stock tomorrow, denoted $K_0(s^t)$.

$$K(i,s^t) = \begin{cases} K_0(s^t) & \text{if} \;\; m^{F'}(i,s^t) = 0 \\ K_1(s^t) & \text{if} \;\; m^{F'}(i,s^t) = 1 \end{cases} \tag{30}$$

These are the capital stocks that firms are born with in the next period.

Firm Value: I will use a ordered triple (m^F, $m^{X'}$, $m^{F'}$) to summarize the labor and investment choices of a firm depending on their last-period MP status, and current export and MP choices respectively. For example, $L_{0,1,0}(i,s^t)$ corresponds to the labor employed by a last-period non-MP firm, which exports today; $L_{0,0,1}(i,s^t)$ corresponds to labor employed by a last-period non-MP firm, which conducts MP today. The investment variable is defined similarly. Using the order triplet helps to define the firms' value function by activity and last-period MP status 31-33, and to define the export and MP productivity cutoff conditions 34-36.

Using this notation, I can write firms' current value conditional on last-period MP status m^F, current productivity η, and aggregate conditions s^t. The value of a domestic-only producer is,

$$\begin{aligned} V^D(\eta, K_{m^F}, m^F, s^t) = \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)L_{m^F,0,0}(i,s^t) - P(s^t)x_{m^F,0,0}(i,s^t) \\ + \sum_{s^{t+1}} \sum_{\eta'} Q(s^{t+1}|s^t)Pr(\eta')V(\eta', K_0', 0, s^{t+1}) \end{aligned} \tag{31}$$

Where the $L_{m^F,0,0}$ can be derived from plugging $m^{X'} = 0$ in 20, and $x_{m^F,0,0}(i,s^t) = K_0(s^t) - (1-\delta_k)K_{m^F}(s^{t-1})$ is the investment given capital mass-points 30. The value of an exporter is,

$$\begin{aligned} V^X(\eta, K_{m^F}, m^F, s^t) = \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)L_{m^F,1,0}(i,s^t) - q(s^t)P(s^t)W^\star(s^t)\frac{F^X}{\phi} \\ - P(s^t)x_{m^F,1,0}(i,s^t) + \sum_{s^{t+1}} \sum_{\eta'} Q(s^{t+1}|s^t)Pr(\eta')V(\eta', K_0', 0, s^{t+1}) \end{aligned} \tag{32}$$

Where the $L_{m^F,1,0}$ can be derived from plugging $m^{X'} = 1$ in 20, and $x_{m^F,1,0}(i,s^t) = K_0(s^t) - (1-\delta_k)K_{m^F}(s^{t-1})$ is the investment given capital mass-points 30; and $\phi = 1$ if $m^F = 0$ and $\phi > 1$ (as calibrated) if $m^F = 1$. And finally, the value of an MP firm today is,

$$\begin{aligned} V^F(\eta, K_{m^F}, m^F, s^t) = \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)\left[L^D_{m^F,0,1}(i,s^t) + \frac{q(s^t)W^\star(s^t)}{W(s^t)}L^F_{m^F,0,1}(i,s^t)\right] \\ - q(s^t)P(s^t)W^\star(s^t)\left[F_1^F + (1-m^F)F_0^F\right] - P(s^t)x_{m^F,0,1}(i,s^t) + \\ \sum_{s^{t+1}} \sum_{\eta'} Q(s^{t+1}|s^t)Pr(\eta')V(\eta', K_1', 1, s^{t+1}) \end{aligned} \tag{33}$$

Where labor demands $L^D_{m^F,0,1}$ (MP parent's labor demand), and $L^{D\star}_{m^F,0,1}$ (MP affiliate's labor demand) can be inferred from 25 and 26 respectively; $x_{m^F,0,1}(i,s^t) = K_1(s^t) - (1-\delta_k)K_{m^F}(s^{t-1})$ is the firms' investment.

The condition for marginal exporter 15 can be re-written using the domestic and exporters' value functions (31 and 32) as

$$\begin{aligned} 0 = \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)\left[L_{m^F,1,0}(i,s^t) - L_{m^F,0,0}(i,s^t)\right] - q(s^t)P(s^t)W^\star(s^t)\frac{F^X}{\phi} \\ + P(s^t)\left[x_{m^F,0,0}(i,s^t) - x_{m^F,1,0}(i,s^t)\right] + \sum_{s^{t+1}} \sum_{\eta'} Q(s^{t+1}|s^t)Pr(\eta')\left[V(\eta', K_0', 0, s^{t+1}) - V(\eta', K_0', 0, s^{t+1})\right] \end{aligned}$$

where $\phi = 1$ if $m^F = 0$ and $\phi > 1$ (as calibrated) if $m^F = 1$. Note that capital stock in a period is independent on current export status. As a result, investment is depends only on current last period and current MP choices (m^F and $m^{F'}$). Therefore, $x_{m^F,0,0}(i,s^t) = x_{m^F,1,0}(i,s^t)$.

$$\begin{aligned} \frac{q(s^t)W^\star(s^t)}{W(s^t)}\frac{F^X}{\phi} &= \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)}\left[L_{m^F,1,0}(i,s^t) - L_{m^F,0,0}(i,s^t)\right] \\ &= \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} A(i,s^t)^{\frac{1-\nu}{\alpha}} K_{m^F}(s^{t-1})^{1-\nu}\left[H^\star_{hx}(s^t) - H_h(s^t)\right] \end{aligned} \tag{34}$$

where $\phi = 1$ if $m^F = 0$ and $\phi > 1$ (as calibrated) if $m^F = 1$. Equation 34 shows that given a firm does not choose to conduct MP, the exporting decision is static.

The marginal continuing MP firm's condition is $0 = V^F(\eta_1^F, K_1, 1, s^t) - V^X(\eta_1^F, K_1, 1, s^t)$. Also, $x_{1,1,0}(i,s^t) = K_0(s^t) - (1-\delta_k)K_1(s^{t-1})$ and $x_{1,0,1}(i,s^t) = K_1(s^t) - (1-\delta_k)K_1(s^{t-1})$. For such a firm,

$$\begin{aligned} 0 = \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)&\left[L^D_{m^{F'}=1}(i,s^t) + \frac{q(s^t)W^\star(s^t)}{W(s^t)} L^{D\star}_{m^{F'}=1}(i,s^t) - L_{1,1,0}(i,s^t)\right] \\ &- q(s^t)P(s^t)W^\star(s^t)\left[F_1^F - \frac{F^X}{\phi}\right] - P(s^t)\left[K_1(s^t) - K_0(s^t)\right] \\ &+ \sum_{s^{t+1}}\sum_{\eta'} Q(s^{t+1}|s^t)Pr(\eta')\left[V(\eta', K_1', 1, s^{t+1}) - V(\eta', K_0', 0, s^{t+1})\right] \end{aligned} \tag{35}$$

For the marginal new MP firm, $0 = V^F(\eta_0^F, K_0, 0, s^t) - V^X(\eta_0^F, K_0, 0, s^t)$. Which simplifies to,

$$\begin{aligned} 0 = \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)&\left[L^D_{m^{F'}=1}(i,s^t) + \frac{q(s^t)W^\star(s^t)}{W(s^t)} L^{D\star}_{m^{F'}=1}(i,s^t) - L_{0,1,0}(i,s^t)\right] \\ &- q(s^t)P(s^t)W^\star(s^t)\left[F_1^F + F_0^F - F^X\right] - P(s^t)\left[K_1(s^t) - K_0(s^t)\right] \\ &+ \sum_{s^{t+1}}\sum_{\eta'} Q(s^{t+1}|s^t)Pr(\eta')\left[V(\eta', K_1', 1, s^{t+1}) - V(\eta', K_0', 0, s^{t+1})\right] \end{aligned} \tag{36}$$

Aggregation: Given the cutoffs, I can write the laws of motion for number of exporters and MP firms originating in each country, $N^X(s^t)$ and $N^F(s^t)$. Among the non-MP firms last-period, a fraction $1 - \Phi(\eta_0^F(s^t))$ conduct MP today; among MP firms a fraction $1 - \Phi(\eta_1^F(s^t))$ conduct MP today. Then,

$$N^F(s^t) = \left[1 - \Phi(\eta_1^F(s^t))\right] N^F(s^{t-1}) + \left[1 - \Phi(\eta_0^F(s^t))\right](1 - N^F(s^{t-1})) \tag{37}$$

Similarly, among the non-MP firms last-period, a fraction $\Phi(\eta_0^F(s^t)) - \Phi(\eta_0^X(s^t))$ conduct MP today; among MP firms a fraction $\Phi(\eta_1^F(s^t)) - \Phi(\eta_1^X(s^t))$ conduct MP today. Then,

$$N^X(s^t) = \left[\Phi(\eta_1^F(s^t)) - \Phi(\eta_1^X(s^t))\right] N^F(s^{t-1}) + \left[\Phi(\eta_0^F(s^t)) - \Phi(\eta_0^X(s^t))\right]\left[1 - N^F(s^{t-1})\right] \tag{38}$$

Using the numbers of exporters and MP firms, I can write the aggregates for capital, investment, labor demand, and the value of firms.

Capital: Among this period firms, all non-MP firms choose a capital stock K_0, while all MP firms choose a capital stock K_1. Therefore,

$$K(s^t) = \left[1 - N(s^t)\right] K_0(s^t) + N(s^t)K_1(s^t) \tag{39}$$

Investment: Aggregate investment at Home is then a difference between the total capital stock chosen today, and the undepreciated capital from last period:

$$X(s^t) = K(s^t) - (1-\delta_k)K(s^{t-1}) \tag{40}$$

Labor demands in home: Home labor is utilized for: 1. production by Home-owned firms for domestic production and exporting, and by Home affiliates of Foreign firms, and 2. fixed cost payments by Home exporters and by Home affiliates of Foreign firms. I will compute the average labor demand in Home and Foreign for production by last-period Home-owned non-MP and MP firms, $L_0^D(s^t)$, $L_1^D(s^t)$, $L_0^F(s^t)$, and $L_1^F(s^t)$:

$$L_0^D(s^t) = \frac{\int_{i\notin\xi^F(s^{t-1})} L(i,s^t)di}{1-N^F(s^{t-1})}, \qquad L_1^D(s^t) = \frac{\int_{i\in\xi^F(s^{t-1})} L(i,s^t)di}{N^F(s^{t-1})}$$

$$L_0^{D\star}(s^t) = \frac{\int_{i\notin\xi^F(s^{t-1})} L_{m^{F'}=1}^{D\star}(i,s^t)di}{1-N^F(s^{t-1})}, \qquad L_1^{D\star}(s^t) = \frac{\int_{i\in\xi^F(s^{t-1})} L_{m^{F'}=1}^{D\star}(i,s^t)di}{N^F(s^{t-1})}$$

Because η is distributed i.i.d, last period MP- and non-MP firms have the same distribution today. In other words, the probability that a firm with a productivity η today was an MP-firm last period is $N^F(s^{t-1})$. Conditional on last-period MP status m^F, I can write the average labor in Home by Home firms as as a sum of domestic-only firms' labor demand (integrate 20 with $m^{X'}=0$ over $-\infty$ to $\eta_{m^F}^X$), exporters' labor demand (integrate 20 with $m^{X'}=1$ over $\eta_{m^F}^X$ to $\eta_{m^F}^F$), and the Home labor demand by Home owned MP firms (integrate 25 over $\eta_{m^F}^F$ to ∞), divided by the number of firms with MP status m^F last-period. This simplifies to,

$$L_{m^F}^D(s^t) = K_{m^F}(s^{t-1})^{1-\nu}\exp\left(Z(s^t)(1-\nu)/\alpha\right) \times \left\{ H_h(s^t)\int_{-\infty}^{\eta_{m^F}^X} \exp\left(\frac{\eta(1-\nu)}{\alpha}\right)\Upsilon(\eta)d\eta \right.$$
$$\left. + H_{hx}^\star(s^t)\int_{\eta_{m^F}^X}^{\eta_{m^F}^F} \exp\left(\frac{\eta(1-\nu)}{\alpha}\right)\Upsilon(\eta)d\eta + \frac{H_h(s^t)}{[1+G(s^t)]^{1-\nu}}\int_{\eta_{m^F}^F}^{\infty} \exp\left(\frac{\eta(1-\nu)}{\alpha}\right)\Upsilon(\eta)d\eta \right\} \quad (41)$$

Where $\Upsilon(\eta)$ is the p.d.f of η. The average of Home-owned MP firms' labor demand in Foreign, conditional on last-period MP status m^F, is the sum of 26 between $\eta_{m^F}^F$ to ∞, divided by the number of firms with MP status m^F last-period,

$$L_{m^F}^{D\star}(s^t) = \left[K_{m^F}(s^{t-1})\frac{G(s^t)}{1+G(s^t)}\right]^{1-\nu}\left(\frac{\exp\left(\zeta Z(s^t)+(1-\zeta)Z^\star(s^t)\right)}{h}\right)^{\frac{1-\nu}{\alpha}}$$
$$\times H_m^\star(s^t)\int_{\eta_{m^F}^F}^{\infty}\exp\left(\frac{\eta(1-\nu)}{\alpha}\right)\Upsilon(\eta)d\eta \quad (42)$$

The total demand in Home labor is then a sum of the operational labor demands and fixed cost labor demands by firms producing in Home:

$$L(s^t) = \left[1-N^F(s^{t-1})\right]L_0^D(s^t) + N^F(s^{t-1})L_1^D(s^t) + \left[1-N^{F\star}(s^{t-1})\right]L_0^F(s^t)$$
$$+ N^{F\star}(s^{t-1})L_1^F(s^t) + L_{fc}(s^t) \quad (43)$$

where $L_{fc}(s^t)$ is the total fixed costs paid in Home labor, which includes fixed cost payments by Foreign exporters, and fixed and sunk cost payments by Foreign MP firms.

$$L_{fc}(s^t) = \frac{F^X}{\phi}N^{X\star}(s^t) + \int_{i\in\xi^{F\star}(s^t)}\left\{[1-m^{F\star}(i,s^{t-1})](F_1^F+F_0^F) + m^{F\star}(i,s^{t-1})F_1^F\right\}di$$

Because firm productivity is distributed i.i.d., firms' productivity today is independent of their productivity last period. As a result, a constant fraction $N^F(s^{t-1})$ of today's MP firms conducted MP last period. These MP firms do not pay the sunk cost today, while the other MP firms do,

$$L_{fc}(s^t) = F^X N^{F\star}(s^{t-1})\left[\Phi(\eta_0^{F\star}(s^t)) - \Phi(\eta_0^{X\star}(s^t))\right] + \frac{F^X}{\phi}(1-N^{F\star}(s^{t-1}))\left[\Phi(\eta_1^{F\star}(s^t)) - \Phi(\eta_1^{X\star}(s^t))\right]$$
$$+ F_1^F + F_0^F(1-N^{F\star}(s^{t-1}))\left[1-\Phi(\eta_0^{F\star}(s^t))\right] + F_1^F N^{F\star}(s^{t-1})\left[1-\Phi(\eta_1^{F\star}(s^t))\right] \quad (44)$$

Profits: Let $\Pi_{m^F}(s^t)$ be the aggregate profit of all firms with MP status m^F last period.

$$\Pi_0(s^t) = \frac{\int_{i\notin\xi^F(s^{t-1})}\Pi(i,s^t)di}{1-N^F(s^{t-1})}, \qquad \Pi_1(s^t) = \frac{\int_{i\in\xi^F(s^{t-1})}\Pi(i,s^t)di}{N^F(s^{t-1})}$$

Given m^F, $\Pi_{m^F}(s^t)$ is the sum of domestic firms' profits 12 integrated between $-\infty$ to $\eta_{m^F}^X$, exporters' profits 13 integrated between $\eta^X_{m^F}$ to $\eta^F_{m^F}$, and MP firms' profits 14 integrated between $\eta^F_{m^F}$ to ∞, divided by the number of firms with MP status m^F last-period,

$$\begin{aligned}\Pi_{m^F}(s^t) = {} & \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)\left[L^D_{m^F}(s^t) + \frac{q(s^t)W^\star(s^t)}{W(s^t)} L^{D\star}_{m^F}(s^t)\right] \\ & - q(s^t)P(s^t)W^\star(s^t)\left\{\frac{F^X}{\phi}\left[\Phi(\eta^F_{m^F}) - \Phi(\eta^X_{m^F})\right] + \left(F^F_1 + (1-m^F)F^F_0\right)\left[1-\Phi(\eta^F_{m^F})\right]\right\} \\ & - P(s^t)\left\{[1-\Phi(\eta^F_{m^F})]K_1(s^t) + \Phi(\eta^F_{m^F})K_0(s^t) - (1-\delta_k)K_{m^F}(s^{t-1})\right\}\end{aligned}$$

where $\phi = 1$ if $m^F = 0$ and $\phi > 1$ (as calibrated) if $m^F = 1$.

The total profits of all firms originating in Home, including the profits of affiliates earned abroad, is,

$$\Pi(s^t) = [1 - N^F(s^{t-1})]\Pi_0(s^t) + N^F(s^{t-1})\Pi_1(s^t) \tag{45}$$

Prices: Before I aggregate firm prices, I will rewrite firm prices in 17-19. Plugging into 17 the marginal product of labor $F^D_l(i,s^t) = (1-\alpha)A_{hh}(i,s^t)\left(\frac{K(i,s^{t-1})}{L(i,s^t)}\right)^\alpha$, where $L(i,s^t)$ is given by 20, I get the Home price of domestic firms and exporters,

$$\left(\frac{P_{m^{F'}=0}(i,s^t)}{P(s^t)}\right)^{\frac{\theta}{\theta-1}} = \left(\frac{W(s^t)}{\theta(1-\alpha)}\right)^{\frac{\theta}{\theta-1}} A_{hh}(i,s^t)^{\frac{1-\nu}{\alpha}} K_{m^F}(s^{t-1})^{1-\nu} H^{\frac{\nu-1}{\nu}} \tag{46}$$

Note that the price is raised to the power $\theta/(\theta-1)$, which results in the exponents on the right hand side.

MP firms, on the other hand, use only a fraction of their capital in the parent firm. This affects the marginal product of labor, giving the following expression for their Home price,

$$\left(\frac{P^D_{m^{F'}=1}(i,s^t)}{P(s^t)}\right)^{\frac{\theta}{\theta-1}} = \left(\frac{W(s^t)}{\theta(1-\alpha)}\right)^{\frac{\theta}{\theta-1}} A_h(i,s^t)^{\frac{1-\nu}{\alpha}} \left(\frac{K_{m^F}(s^{t-1})}{1+G(s^t)}\right)^{1-\nu} H_h(s^t)^{\frac{\nu-1}{\nu}} \tag{47}$$

The CES aggregate of the Home prices of Home firms (raised to exponent $\theta/(\theta-1)$) is then,

$$\left(\frac{P_h(s^t)}{P(s^t)}\right)^{\frac{\theta}{\theta-1}} = \int_i \left(\frac{P_h(i,s^t)}{P(s^t)}\right)^{\frac{\theta}{\theta-1}} di$$

Which equals the sum of the firm prices integrated over the productivity ranges for domestic firms (with $m^{X'} = 0$ in 46) and exporters (with $m^{X'} = 1$ in 46), and 47 summed over the productivity range for MP firms,

$$\left(\frac{P_h(s^t)}{P(s^t)}\right)^{\frac{\theta}{\theta-1}} = \left[\int_{i\in\xi^D(s^t)} + \int_{i\in\xi^X(s^t)} + \int_{i\in\xi^F(s^t)}\right]\left(\frac{P_h(i,s^t)}{P(s^t)}\right)^{\frac{\theta}{\theta-1}} di$$

Because the productivity ranges and the capital stocks depend on last-period MP status, I integrate above expression separately for last-period MP firms ($N^F(s^{t-1})$ in number) and non-MP firms ($1 - N^F(s^{t-1})$ in number), and add them together,

$$\left(\frac{P_h(s^t)}{P(s^t)}\right)^{\frac{\theta}{\theta-1}} = \left(\frac{W(s^t)}{\theta(1-\alpha)}\right)^{\frac{\theta}{\theta-1}} \exp\left(Z(s^t)(1-\nu)/\alpha\right) \times \Bigg\{ K_0(s^{t-1})^{1-\nu}[1-N^F(s^{t-1})]$$
$$\Bigg[H_h^{\frac{\nu-1}{\nu}} \int_{-\infty}^{\eta_0^X(s^t)} \exp\left(\frac{1-\nu}{\alpha}\eta\right)\Upsilon(\eta) + H_{hx}^{\star\frac{\nu-1}{\nu}} \int_{\eta_0^X(s^t)}^{\eta_0^F(s^t)} \exp\left(\frac{1-\nu}{\alpha}\eta\right)\Upsilon(\eta) +$$
$$\frac{H_h^{\frac{\nu-1}{\nu}}}{(1+G(s^t))^{1-\nu}} \int_{\eta_0^F(s^t)}^{\infty} \exp\left(\frac{1-\nu}{\alpha}\eta\right)\Upsilon(\eta) \Bigg]$$
$$+ K_1(s^{t-1})^{1-\nu} N^F(s^{t-1}) \Bigg[H_h^{\frac{\nu-1}{\nu}} \int_{-\infty}^{\eta_1^X(s^t)} \exp\left(\frac{1-\nu}{\alpha}\eta\right)\Upsilon(\eta) + H_{hx}^{\star\frac{\nu-1}{\nu}} \int_{\eta_1^X(s^t)}^{\eta_1^F(s^t)} \exp\left(\frac{1-\nu}{\alpha}\eta\right)\Upsilon(\eta)$$
$$+ \frac{H_h^{\frac{\nu-1}{\nu}}}{(1+G(s^t))^{1-\nu}} \int_{\eta_1^F(s^t)}^{\infty} \exp\left(\frac{1-\nu}{\alpha}\eta\right)\Upsilon(\eta) \Bigg] \Bigg\} \quad (48)$$

To derive the the Home exporters and MP firms' price index in Foreign, I will rewrite their individual firm prices. Exporters charge a markup over their domestic price, adjusted for the exchange rate,

$$\frac{P_{xf}^\star(i,s^t)}{P^\star(s^t)} = \frac{P_h(i,s^t)}{P(s^t)} \frac{\tau}{q(s^t)} \quad (49)$$

The aggregate exporter price index is then,

$$\left(\frac{P_{xf}^\star(s^t)}{P^\star(s^t)}\right)^{\frac{\theta}{\theta-1}} = \int_{i\in\xi^X(s^t)} \left(\frac{P_{xf}^\star(i,s^t)}{P^\star(s^t)}\right)^{\frac{\theta}{\theta-1}} di$$

$$= \left(\frac{\tau}{q(s^t)}\frac{W(s^t)}{\theta(1-\alpha)}\right)^{\frac{\theta}{\theta-1}} H_{hx}^{\star\frac{\nu-1}{\nu}} \exp\left(\frac{Z(s^t)(1-\nu)}{\alpha}\right) \Bigg\{ K_0(s^{t-1})^{1-\nu}[1-N^F(s^{t-1})]$$
$$\times \int_{\eta_0^X}^{\eta_0^F} \exp\left(\eta(1-\nu)/\alpha\right)\Upsilon(\eta)d\eta + K_1(s^{t-1})^{1-\nu}N^F(s^{t-1}) \int_{\eta_1^X}^{\eta_1^F} \exp\left(\eta(1-\nu)/\alpha\right)\Upsilon(\eta)d\eta \Bigg\} \quad (50)$$

And the price charged in the foreign market by an MP firm is obtained by plugging in $F_l(i,s^t) = (1-\alpha)A_{hf}(i,s^t)\left(\frac{L^{D\star}(i,s^t)}{K^{D\star}(i,s^t)}\right)^{1-\alpha}$ into 19, where $L^{D\star}(i,s^t)$ and $K^{D\star}(i,s^t)$ are given by 26 and 29,

$$\left(\frac{P^{D\star}_{mF'=1}(i,s^t)}{P^\star(s^t)}\right)^{\frac{\theta}{\theta-1}} = \left(\frac{W^\star(s^t)}{\theta(1-\alpha)}\right)^{\frac{\theta}{\theta-1}} A_{hf}(i,s^t)^{\frac{1-\nu}{\alpha}} K^{D\star}_{mF'=1}(i,s^t)^{1-\nu} H_h^\star(s^t)^{\frac{\nu-1}{\nu}} \quad (51)$$

The aggregate of multinational affiliates' price in Foreign is then,

$$\left(\frac{P_{mf}^\star(s^t)}{P^\star(s^t)}\right)^{\frac{\theta}{\theta-1}} = \int_{i\in\xi^M(s^t)} \left(\frac{P_{mf}^\star(i,s^t)}{P^\star(s^t)}\right)^{\frac{\theta}{\theta-1}} di$$

$$= \left(\frac{W^\star(s^t)}{\theta(1-\alpha)}\right)^{\frac{\theta}{\theta-1}} \left(\frac{\exp\left(\zeta Z(s^t)+(1-\zeta)Z^\star(s^t)\right)}{h}\right)^{\frac{1-\nu}{\alpha}} H_m^\star(s^t)^{\frac{\nu-1}{\nu}} \left(\frac{G(s^t)}{1+G(s^t)}\right)^{1-\nu}$$
$$\times \Bigg\{ K_0(s^{t-1})^{1-\nu}[1-N^F(s^{t-1})] \int_{\eta_0^F}^{\infty} \exp\left(\eta(1-\nu)/\alpha\right)\Upsilon(\eta)d\eta$$
$$+ K_1(s^{t-1})^{1-\nu}N^F(s^{t-1}) \times \int_{\eta_1^F}^{\infty} \exp\left(\eta(1-\nu)/\alpha\right)\Upsilon(\eta)d\eta \Bigg\} \quad (52)$$

Home aggregate price 6 can then be rewritten as,

$$1 = \delta_h^{\frac{1}{1-\rho}} \left(\frac{P_h(s^t)}{P(s^t)}\right)^{\frac{\rho}{\rho-1}} + \delta_x^{\frac{1}{1-\rho}} \left(\frac{P_{xf}(s^t)}{P(s^t)}\right)^{\frac{\rho}{\rho-1}} + (1-\delta_h-\delta_x)^{\frac{1}{1-\rho}} \left(\frac{P_{mf}(s^t)}{P(s^t)}\right)^{\frac{\rho}{\rho-1}} \tag{53}$$

where the individual price ratios within the above equation are given by 48 and the foreign equivalents of 50 and 52 (which is the price relevant for the Home final good aggregator).

Firm Value and Cutoffs: I specify the cutoff conditions 34, 35, and 36 in terms of average values that can be tracked over time. I define $V_{m^F}(s^t)$ as the average value today of all firms that had the MP status m^F last period.

$$V_0(s^t) = \frac{1}{1-N^F(s^{t-1})} \int_{i\notin\xi^F(s^{t-1})} V(\eta, K_0(s^{t-1}), 0, s^t) di$$

$$V_1(s^t) = \frac{1}{N^F(s^{t-1})} \int_{i\in\xi^F(s^{t-1})} V(\eta, K_1(s^{t-1}), 1, s^t) di$$

$V_{m^F}(s^t)$ is then a sum of $V^D(i,s^t)$ in 31 over the productivity range of domestic firms, $V^X(i,s^t)$ in 32 over the productivity range of exporters, and $V^F(i,s^t)$ in 33 over the productivity range of MP firms, each with last-period MP status m^F. In general form, this simplifies to,

$$\begin{aligned} V_{m^F}(s^t) = {} & \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)\left[L^D_{m^F}(s^t) + \frac{q(s^t)W^\star(s^t)}{W(s^t)} L^{D\star}_{m^F}(s^t)\right] \\ & - q(s^t)P(s^t)W^\star(s^t)\left[\{\Phi(\eta^F_{m^F}) - \Phi(\eta^X_{m^F})\}\frac{F^X}{\phi} + \{1-\Phi(\eta^F_{m^F})\}\left(F^F_1 + (1-m^F)F^F_0\right)\right] \\ & - P(s^t)\left\{\Phi(\eta^F_{m^F})K_0(s^t) + [1-\Phi(\eta^F_{m^F})]K_1(s^t)\right\} + P(s^t)(1-\delta_k)K_{m^F}(s^{t-1}) \\ & + \sum_{s^{t+1}} Q(s^{t+1}|s^t)\left\{\Phi(\eta^F_{m^F})V_0(s^{t+1}) + [1-\Phi(\eta^F_{m^F})]V_1(s^{t+1})\right\} \end{aligned} \tag{54}$$

where $\phi = 1$ if $m^F = 0$ and $\phi > 1$ (as calibrated) if $m^F = 1$. I will now compute the difference in average values today of last period MP and non-MP firms. This difference can be plugged into modified MP cutoff conditions 36 and 35 to derive cutoff conditions that are tractable over time,

$$\begin{aligned} V_1(s^t) - V_0(s^t) = {} & \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)\left[L^D_1(s^t) - L^D_0(s^t) + \frac{q(s^t)W^\star(s^t)}{W(s^t)}\left(L^{D\star}_1(s^t) - L^{D\star}_0(s^t)\right)\right] \\ & - q(s^t)P(s^t)W^\star(s^t)\Big[\frac{F^X}{\phi}\{\Phi(\eta^F_1) - \Phi(\eta^X_1)\} - F^X\{\Phi(\eta^F_0) - \Phi(\eta^X_0)\} \\ & + \left\{F^F_1[1-\Phi(\eta^F_1)] - [F^F_1 + F^F_0][1-\Phi(\eta^F_0)]\right\}\Big] \\ & + [\Phi(\eta^F_0) - \Phi(\eta^F_1)]\sum_{s^{t+1}} Q(s^{t+1}|s^t)[V_1(s^{t+1}) - V_0(s^{t+1})] \end{aligned} \tag{55}$$

The marginal MP firm's cutoff conditions 35 and 36 can be rewritten (using m^F as last period MP status) as,

$$\begin{aligned} 0 = {} & \frac{1-\theta(1-\alpha)}{\theta(1-\alpha)} P(s^t)W(s^t)K_{m^F}(s^{t-1})^{1-\nu}\exp\left([Z(s^t) + \eta_{m^F}(s^t)](1-\nu)/\alpha\right) \times \Bigg\{ H_h(s^t)\left(\frac{1}{1+G(s^t)}\right)^{1-\nu} \\ & + \frac{q(s^t)W^\star(s^t)}{W(s^t)} H^\star_m(s^t)\exp\left((1-\zeta)(1-\nu)/\alpha(Z^\star(s^t) - Z(s^t))\right)\left(\frac{G(s^t)}{1+G(s^t)}\right)^{1-\nu} - H^\star_{hx}(s^t)\Bigg\} - \\ & q(s^t)P(s^t)W^\star(s^t)\left[F^F_1 + (1-m^F)F^F_0 - \frac{F^X}{\phi}\right] - \\ & P(s^t)\left[K_1(s^t) - K_0(s^t)\right] + \sum_{s^{t+1}} Q(s^{t+1}|s^t)\left[V_1(s^{t+1}) - V_0(s^{t+1})\right] \end{aligned} \tag{56}$$

Where $V_1(s^{t+1}) - V_0(s^{t+1})$ is given by 55 and $\phi = 1$ if $m^F = 0$ and $\phi > 1$ (as calibrated) if $m^F = 1$.

Capital FOC: And finally, firms choose capital subject to the following first order condition derived by differentiating value function 9 with respect to capital separately for current non-MP ($m^{F'}=0$) and MP ($m^{F'}=1$) firms:

$$1=\sum_{s^{t+1}} Q(s^{t+1}|s^t)\frac{P(s^{t+1})}{P(s^t)}\left[\frac{\alpha}{1-\alpha}\frac{W(s^{t+1})L_{m^{F'}}(s^{t+1})}{K_{m^{F'}}(s^t)}+(1-\delta_k)\right] \tag{57}$$

Where $L_{m^{F'}}(s^{t+1})=L^D_{m^{F'}}(s^t)+\frac{q(s^t)W^\star(s^t)}{W(s^t)}L^{D\star}_{m^{F'}}(s^t)$ is the sum of average labor demands in 41 and 42.

Computing Net Exports and Real Gross Domestic Product

Real domestic production, exports and imports:

$$Y_d(s^t)=\int_i \frac{P_h(i,s^t)y_h(i,s^t)}{P_h(s^t)}=\delta_h^{\frac{1}{1-\rho}}\left(\frac{P_h(s^t)}{P(s^t)}\right)^{\frac{1}{\rho-1}}D(s^t) \tag{58}$$

$$Y_{ex}(s^t)=\int_{i\in\xi^X(s^t)} \frac{e(s^t)P^\star_{xf}(i,s^t)y^\star_{xf}(i,s^t)}{e(s^t)P^\star_{xf}(s^t)}=\delta_x^{\frac{1}{1-\rho}}\left(\frac{P^\star_{xf}(s^t)}{P^\star(s^t)}\right)^{\frac{1}{\rho-1}}D^\star(s^t) \tag{59}$$

$$Y_{im}(s^t)=\int_{i\in\xi^{X\star}(s^t)} \frac{P_{xf}(i,s^t)y_{xf}(i,s^t)}{P_{xf}(s^t)}=\delta_x^{\frac{1}{1-\rho}}\left(\frac{P_{xf}(s^t)}{P(s^t)}\right)^{\frac{1}{\rho-1}}D(s^t) \tag{60}$$

Gross Domestic Product

I compute real gross domestic product (GDP) similar to Alessandria and Choi [2007]. Nominal GDP is is the sum of sales of all goods produced domestically.

$$P_G(s^t)Y(s^t)=\int_0^1[P_h(i,s^t)y_h(i,s^t)+e(s^t)P^\star_{xf}(i,s^t)Y_{ex}(i,s^t)]di+\int_{i\in\xi^{F\star}(s^t)}P_{mf}(i,s^t)y_{mf}(i,s^t)di \tag{61}$$

where the GDP deflator $P_G(s^t)$ is is an aggregation of domestic, export, and foreign MP price indexes,

$$P_G(s^t)=\chi_d(x^t)P_h(s^t)+\chi_x(x^t)P^\star_{xf}(s^t)+[1-\chi_d(x^t)-\chi_x(x^t)]P_{mf}(s^t) \tag{62}$$

The weights on domestic and export price indexes are their respective shares in GDP: $\chi_d(s^t)=\frac{P_h(s^t)y_h(s^t)}{P_G(s^t)Y(s^t)}$ and $\chi_x(s^t)=\frac{e(s^t)P^\star_{xf}(s^t)Y_{ex}(s^t)}{P_G(s^t)Y(s^t)}$.

B Calculating MP Transition Rates

I calculate transition probabilities using Tables 1 and 6 in Boehm et al. [2020]. They provide transition probabilities separately for US headquarterd multinationals and affiliates of foreign multinationals. The transition probabilities for these two types of firms are in the same ballpark, so I take a weighted average of the two types of firms to get a more representative picture. Alternatively, one could simply calculate and plug in the entry and exit rates for US multinationals from Table 6, but this approach leads to very similar transition probabilities (explained below), and the quantitative results do not change.

From Table 1, I calculate the numbers of MP firms as the sum of US multinationals and foreign multinationals. There are two years to choose the number of firms from-1993 and 2011. The number of US multinationals were 2.8 times the number of foreign multinationals in 1993 (17119 US multinationals and 6178 foreign multinationals), compared to 1.5 times in 2011 (13488 US multinationals and 8952 foreign multinationals). By choosing 2013 numbers therefore, the weighted average transition rates are closer to the transition rates of foreign multinationals.

Dealing with exit: Table 6 provides annual transition probabilities by activity averaged over the 1993-2011 time period. Because I do not model exit, I only calculate transition probabilities for surviving firms. 6.06% of US multinationals and 5.7% of foreign multinationals exit. This gives the weighted average survival rate of 94.08%. Similarly, the number of surviving domestic firms and exporters are 90.07% and 94.71% respectively.

Calculating MP exit rate: Among all US multinationals, 0.27% enter domestic only market and 1.85% become exporters. Among all foreign multinationals, 0.45% enter domestic only market and 1.94% become exporters. The weighted average transition probability to domestic only market is 0.37% after accounting for exit. The weighted average transition probability to export market is 2%. The MP exit rate, which is the sum of transition probabilities to domestic only market and export market, is therefore 2.37%, which in quarterly terms is 0.5919%.

Calculating MP entry rate: Firms can enter MP status from past domestic or export statuses. The calculation here is simpler because I do not need to consider transition probabilities of foreign firms or the number of foreign firms. Among all domestic only firms, 0.03% become US multinationals; among all exporters, 0.84% become US multinationals. The weighted average MP entry rate, as a fraction of surviving domestic-only firms and exporters, is therefore 0.2952% per year. In quarterly terms, it is 0.0738% per year.