# Global Production with Export Platforms

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**Abstract**

This paper develops and estimates a model of firms' global location and production decisions. In the model, firms incur fixed costs to set up foreign plants. Foreign plants can be used as export platforms to serve surrounding markets. This generates a large discrete choice problem at the firm level. The decision about from where to serve which market is interdependent across markets and products. However, the model delivers elegant and intuitive expressions for the output at the plant-level conditional on a firm's location choice. I use both firm-level and aggregate data to address two sets of questions: (1) What are the sources of significant home bias in production of multinational firms? My structural estimates from location and output data of German multinational firms suggest that fixed costs and larger variable production costs abroad are about equally important. (2) How does multinational production affect welfare? I calibrate the general equilibrium outcomes of the model to match trade and multinational production data for twelve Western European and North American countries. Counterfactual results reveal that multinationals play an important role in transmitting technological improvements to foreign countries. Furthermore, the Canada-EU free trade and investment agreement currently being negotiated could divert around seven percent of the production of EU multinationals from the US to Canada.

*JEL Codes:* F12, F23, L23
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# 1 Introduction

Multinational production has outgrown international trade over the last few decades. Nowadays, the value of U.S. multinational firms' production abroad is more than twice as large as the value of aggregate U.S. exports. Firms are increasingly thinking of the whole world as their production location and market - firms are getting globalized, so that just like a firm in the U.S. chooses domestically where to produce and sell, now firms behave like that but in the whole world. In contrast, workers are not: they are still stuck to domestic territory. So the question arises as to how the globalization of firms affects welfare and policy when workers are not yet globalized.

In order to investigate those questions, what ingredients should a model of multinational production have? Most firms concentrate their production in a few locations. This suggests that the model should incorporate a fixed cost for a firm to set up a foreign plant.[1] Furthermore, multinational firms tend to use a production plant in a foreign country not only to serve the local market but also surrounding markets as well. Figure 1 documents the proportion of output of US multinationals' affiliates in Europe exported to countries other than the host country or the United States (called export platform sales). US multinationals sell on average around 40 percent of the foreign output to countries other than the local market. This share is systematically higher for smaller countries. It seems implausible to assume that the anticipation of these sales didn't affect location or production decisions. Hence, the model should allow for the possibility of export platform sales.

Fixed cost for each foreign plant together with export platform sales greatly complicate the problem of the firm. With fixed costs per country and export platforms, the decision about from where to serve which market is interdependent across markets. For instance if Belgium is served from France, France may be also served from France as the fixed cost to set up a plant in France has already been incurred. For a single product firm this generates $N^N$ possible market supply choices (where $N$ denotes the number of countries) - a seemingly intractable number of choices. The model in this paper overcomes this seeming intractability of fixed costs and export platforms and enables an analysis that acknowledges the complex problem of the firm, can be solved in general equilibrium, and applied empirically to data of many countries.

The starting point for my analysis is a Melitz type model with heterogeneous firms, monopolistic competition, and trade costs.[2] As in Helpman, Melitz, and Yeaple (2004), I allow firms to set up foreign plants. However, I depart from them in allowing firms to use their foreign plants to serve surrounding export markets.

In order to set up a foreign plant a firm must incur a fixed cost that can vary across country pairs.

[1] An alternative explanation for concentration in production is that firms receive different productivity draws across the globe and concentrate their production in locations with a high productivity draw. However, without fixed costs this hypothesis is inconsistent with the empirical fact that multinational firms tend to be larger than their purely domestic peers. This fact suggests that only above a certain size threshold it is profitable to become a multinational firm.

[2] Unlike Melitz (2003) and Chaney (2008), I abstract from fixed costs of exporting. I lack the firm-level export sales data needed to identify such costs and I consider them as second order relative to the fixed costs of setting up foreign plants.

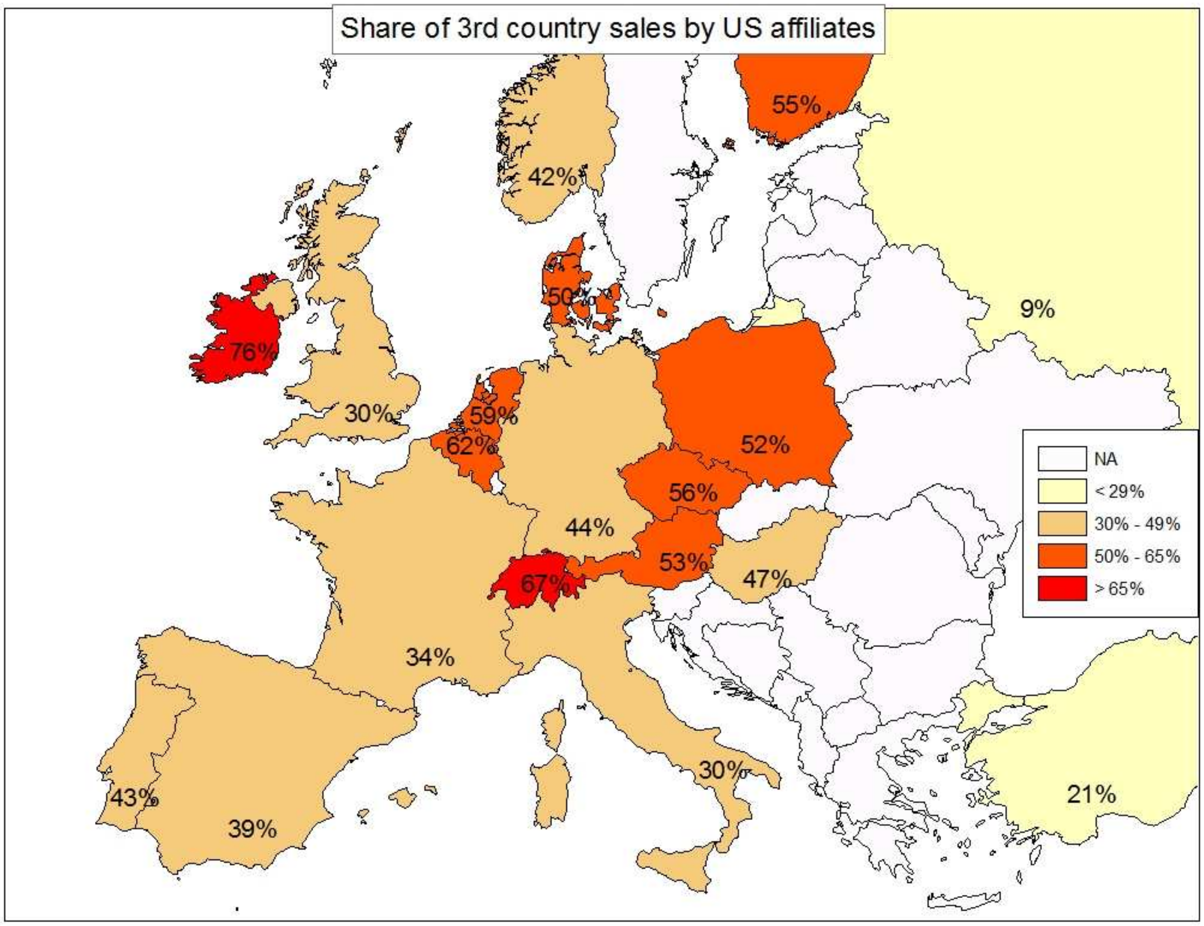


Figure 1: Export platform shares for US multinationals in Europe (year: 2004, source: BEA)

This fixed cost captures both physical costs and informational barriers to set up a foreign plant. Similarly, communication costs with headquarters may affect the variable production costs of the foreign plant. I therefore allow for efficiency losses in moving production outside the firm's home country. Again, those frictions can vary by source and destination country.

I make the following assumptions on firm heterogeneity: Firms differ in their core productivity levels. A firm's core productivity and the firm-destination specific level of fixed costs are observed by the firm. The firm then selects its production locations based on maximizing expected profits. If there were no heterogeneity in fixed costs, the model would deliver a perfect pecking order of location choices. For example, every multinational from Germany with a single foreign plant would have this plant in the U.S.. Heterogeneity in fixed costs across firms reconcile the model with observations on firms' diverse location choices. After the production locations are selected the firm learns its country-specific productivity shifters and makes its final output decisions. Location-specific productivity shifters ensure that I can rationalize the output data. Without them, the relative output of two different firms with the same choice of production locations would be the same in every country.[3]

I assume every firm produces a continuum of products. Every product is distinct. For each product the firm receives a location-specific productivity which depends on both the core productivity of the firm and the country specific productivity shifter. The assumption of a continuum of products not only reflects recent evidence that most firms produce multiple products, but also delivers simple closed-form expressions for the output at the plant level given a firm's location choice.[4]

The assumptions on a continuum of products per firm together with location specific productivity draws for each product greatly simplify the complex problem of a firm. Conditional on a chosen vector of production locations, the decision of which market to serve from where is independent across markets. With a single product firm, one does not gain from splitting one large problem into two, as conditional on a chosen vector of production location, there is another layer of discrete choices where to serve which market from without closed-form expressions for sales or profits. However, with a continuum of products and product-location specific productivity draws, I can integrate out the discrete choice problem for each product from where to serve which market. The model delivers closed-form expressions for the sales at the plant-level and profits at the firm-level conditional on the location choice of the firm.[5] The assumption on a continuum of products, reduces the intractable $N^N$ discrete choice problem to a discrete location choice problem with $2^{N-1}$ possible choices - which is still large, but tractable for a moderate number of countries.

In this environment, the different plants of the same firm are potential substitutes in producing each of its products. An implication is that a firm's decisions on output in every plant are interrelated. For each destination market, the the plant level sales depend on the delivery costs from the particular plant relative to all the other plants the firm has. The productivity of one plant affects how much the other plants are used. The sales of a particular plant of a firm are rising in the productivity of the plant and falling in the productivities of the firm's other plants. As a consequence, the decision about where to establish plants in the first place is also interrelated across plants. The firm chooses a vector of production locations (instead of making independent decisions across countries about whether to establish a plant).

The empirical part of the paper starts with the analysis of location choices and output by German multinational firms. I concentrate on the activities in 12 Western European and North American countries as similar capital-labor ratios in these countries suggest that - in line with the theory - most of the FDI between

[3]The timing assumption makes the analysis of the firm-level data more tractable. Under the timing assumption we need to condition for the optimal location choice on the core productivity level of the firm and the vector of fixed costs draws, but not on the vector of productivities in every plant (and the productivity draws in countries in which the firm didn't erect a plant). Furthermore, it is also plausible to think that the firm learns about the exact quality of its plant only after it sunk the costs of erecting a plant.

[4]Recent evidence on the pervasiveness of multi-product firms is provided by Bernard, Jensen, Redding, and Schott (2007), Bernard, Redding, and Schott (2010), and Arkolakis and Muendler (2010).

[5]In my model, each firm is its own little micro-cosmos of Eaton and Kortum (2002).

these countries is driven by horizontal motives.[6] Despite multinational production growing rapidly, firms still show significant home bias in their production. To visualize the home bias in production of multinational firms, consider a world with identical preferences and positive trade costs between countries. Suppose there were neither fixed costs to set up foreign plants nor differences in production costs across countries. Then every firm would be active in every country and the share of each foreign country in the firm's total output would be similar to that country's share in global GDP. If we take Germany as the home country and focus on 12 Western European and North American countries, the average foreign output share of German multinationals in this benchmark should be around 85 percent. In the data however, the average total foreign output share of German multinationals in those countries is only 29 percent.

I estimate relative variable production costs across countries and fixed costs to set up foreign affiliates that maximize the simulated likelihood of my model. Removing in counterfactuals differences in variable production costs and differences in fixed costs allows me to assess the relative importance of each of these frictions. I find that German multinational firms face between 6 percent (Austria) and 39 percent (United States) larger variable production costs abroad than at home. If the variable production costs were the same in foreign countries as in Germany, the foreign output share would rise to 62 percent. If instead variable production costs were at their estimated level and fixed costs to set up foreign plants were eliminated, the foreign output share would be 69 percent. These findings suggest that fixed costs and variable production cost differences are similarly important in explaining home bias in production of multinational firms.

Furthermore, I investigate the welfare predictions of my global production model. I calibrate the general equilibrium of the model to fit data on bilateral aggregate trade flows and foreign production as well as the production cost estimates for German multinationals. For two different welfare questions, I compare the predictions from my calibrated model with the predictions from a pure trade model without multinational production: I find that the gains from trade estimates from a pure trade model without multinational production are very similar to the gains from trade estimates in my global production model. However, I also find that the gains in foreign countries from US firms' technology improvements are an order of magnitude larger in the global production model than in the pure trade model. Export platform sales also matter for policy analysis. Without the possibility of export platform sales, the location and output decisions of European firms are independent between Canada and the United States. In my calibrated model (with the possibility of export platform sales), I find that the currently negotiated Canada-EU Free Trade and Investment Agreement could induce a strong third party effect on the United States. A twenty percent reduction of variable and fixed production costs between the signatories may divert around seven percent of the production of EU multinationals from the US

[6] Analyzing the distribution of US affiliate sales suggests that the assumption that most FDI is horizontal is not a bad one (Blonigen (2005)). The share of sales back to the US from Europe is only 7 percent. For Canada the share of sales back to the U.S. is considerably higher. However, the sales back to the home country could also be driven by a horizontal motive.

to Canada.

I built on a large literature that studies multinational firms. Horstmann and Markusen (1992) develop a model of horizontal FDI with a proximity-concentration trade-off. Firms face a trade-off between investing abroad to avoid marginal costs (proximity to markets) and exporting to avoid fixed costs from additional production locations (concentration). The proximity-concentration trade-off is tested empirically by Brainard (1997). Helpman, Melitz, and Yeaple (2004) develop a model of the proximity-concentration trade-off for heterogeneous firms. Export platform sales are theoretically analyzed in Ekholm, Forslid, and Markusen (2007).[7]

A recent literature on quantitative general equilibrium models of global production allows for export platform sales. However, this literature fits the data on export platform shares for US multinationals only in special cases. Ramondo and Rodriguez-Clare (forthcoming) investigate the gains from trade, multinational production, and openness. Every firm produces a single product. A firm is a vector of productivity draws that is drawn from a multivariate Frechet distribution. Only when productivity draws are uncorrelated within the firm across countries can the calibrated model come close to matching the data on export platform sales for US multinationals. Arkolakis, Ramondo, Rodriguez-Clare, and Yeaple (2012) endogenize the allocation between production and innovation in a model of global production. Their benchmark model generates much lower export platform sales for US firms than in the data. An extension that makes some firms produce goods that can only be sold to the home market improves the fit of export platform sales data. The findings of my paper suggest that maintaining the proximity-concentration trade-off while allowing the possibility of export platform sales is an alternative way to proceed. The existing literature on export platform sales features only variable costs to foreign production to avoid the interdependency across markets. I allow for both fixed and variable costs to foreign production. Both fixed and variable costs tend to discourage foreign production, but fixed costs also give an incentive to concentrate a firm's production in only a few locations.

My paper relates to existing work on structural estimation of the determinants of multinational firms location decisions and production. Irarrazabal, Moxnes, and Opromolla (2009) use data from Norwegian firms and a structural model that is an extension of Helpman, Melitz, and Yeaple (2004) that incorporates intra-firm trade.[8] They estimate fixed costs to set up foreign affiliates and the share of intra-firm trade required to rationalize the observed location and production patterns. Their paper also uses maximum likelihood techniques but the choice problem of the firm is easier as export platform sales are restricted. Therefore in their model, for instance, the decision to set up an affiliate in Belgium is independent of the decision to set up an affiliate in the Netherlands.

[7] Helpman (1984) provides a model of vertical FDI. According to this theory, firms shift production processes into those countries in which they can be produced most cheaply. Production processes differ in their factor intensities and countries differ in their factor endowments. Yeaple (2003) and Grossman, Helpman, and Szeidl (2006) study complex integration strategies of multinational firms.

[8] Instead of assuming intra-firm trade, I allow the production efficiency of foreign affiliates to be different from the production efficiency at home (e.g., through communication costs with headquarters).

This paper also relates to a literature that studies large discrete choice problems at the firm level. Morales, Sheu, and Zahler (2011) estimate a dynamic trade model in which the costs to serve a foreign market are dependent on the set of foreign markets the firm had served in the past. This creates an interdependency of the destination markets. Holmes (2011) estimates the determinants of the roll-out of Walmart stores. Both papers use moment inequalities to conduct the estimation.

My paper contributes to the literature by incorporating both fixed costs to set up a foreign plant and the possibility of export platform sales into a structural model of trade and multinational production. This enables me to give new answers to existing questions such as 'the gains from trade', and 'the gains from foreign technology improvements', as well as address new questions such as 'third-country effects from an investment agreement' and determine 'the sources of home bias in production of multinational firms'.

In the following section I describe the model. Section 3 provides evidence from German multinational firms on 'home bias in production' and estimates country-specific fixed and variable production costs for German multinational firms via constrained maximum likelihood. I conduct counterfactuals on eliminating fixed costs and variable production cost differences across the globe that illustrate the driving forces behind 'home bias in production'. Section 4 calibrates the model to aggregate trade and MP flows between 12 countries and uses the estimates on country-specific production costs for German multinational firms as additional targets. I solve for endogenous price indices and wages and conduct welfare analysis. Specifically I investigate the gains from trade, foreign technology improvement, and the effects from a Canada-EU free trade and investment agreement on the signatories and the United States. Section 5 concludes.

# 2 A model of global production with export platforms

## 2.1 Demand

A good is indexed by a firm $\omega$ and a variety $\upsilon$. There is a measure 1 of varieties per firm. If the representative consumer of country $j$ consumes $q_j(\omega, \upsilon)$ units of each variety $\upsilon$ of each firm $\omega \in \Omega$, she gets the the following utility

$$U^j \equiv \left( \int_{\Omega} \int_{0}^{1} q_j(\omega, \upsilon)^{(\sigma-1)/\sigma} d\upsilon d\omega \right)^{\sigma/(\sigma-1)}. \tag{1}$$

Goods are substitutes and the elasticity of substitution $\sigma > 1$ is identical between varieties inside and outside the firm. Consumers maximize their utility by choosing consumption of goods subject to their budget constraint. I denote aggregate income in country $j$ by $Y_j$.

The quantity demanded in country $j$ of variety $\upsilon$ supplied by firm $\omega$ at price $p_j(\omega,\upsilon)$, is

$$q_j(\omega,\upsilon) = p_j(\omega,\upsilon)^{-\sigma}\frac{Y_j}{P_j^{1-\sigma}}. \tag{2}$$

We can write the price index of firm $\omega$ to country $j$ as

$$p_j(\omega) = \left(\int_0^1 p_j(\omega,\upsilon)^{1-\sigma}d\upsilon\right)^{1/(1-\sigma)} \tag{3}$$

and the overall ideal price index in country $j$ as

$$P_j \equiv \left[\int_{\Omega_j} p_j(\omega)^{(1-\sigma)}d\omega\right]^{1/(1-\sigma)}. \tag{4}$$

The expenditure on goods from firm $\omega$ in country $j$ is

$$s_j(\omega) = p_j(\omega)^{1-\sigma}\frac{Y_j}{P_j^{1-\sigma}}. \tag{5}$$

## 2.2 Production

There are $N$ countries. Country $j$ is endowed with a continuum of heterogeneous firms of mass $M_j$ and a population $L_j$. The market structure is monopolistic competition. Labor is the only factor of production. The wage in country $j$ is denoted by $w_j$.

The production technology is the following: Firms incur a fixed cost, $f_{il}$, to set up a plant in a foreign country (paid in units of labor of the destination country). Conditional on having a plant in a country, the firm faces constant marginal costs to produce in this country. Every firm produces a continuum of products. Firms choose countries in which to produce. Let $Z$ denote an $N$-dimensional vector. If the vector $Z$ contains a plant in country $l$, $Z_l = 1$. $Z_j = 0$ denotes that the vector $Z$ doesn't contain a plant in country $j$. I assume that a firm always has a plant in its home country. Hence if a firm is from country $i$, a vector $Z$ is feasible only if $Z_i = 1$. I denote the feasible set of location vectors for a firm from country $i$ by $\mathcal{Z}^i$. The set $\mathcal{Z}^i$ contains $2^{N-1}$ elements.

A firm is characterized by its country of origin, $i$, its core productivity parameter, $\phi$, a vector of fixed cost shocks in every country, $\eta$, and a vector of location-specific productivity shifters, $\epsilon$. Both $\phi$ and $\epsilon_l$ determine how good the product-specific productivity draws in country $l$ are. More formally, a firm is a tuple $(i,\phi,\eta,\epsilon)$. The country of origin, $i$, is an integer in the set $\{1,...,N\}$. I assume $\eta$ is drawn from a distribution that is continuous and has the positive orthant as its support. $\phi$ and $\epsilon$ can be realizations of arbitrary (potentially degenerate) distributions.

The timing is as follows:

1. $i, \phi, \eta$ are known to the firm before it chooses its vector of production locations. The firm chooses the vector of locations $Z \in \mathcal{Z}^i$ that maximizes its expected profits. The firm incurs fixed costs equal to $\sum_l f_{il}\eta_l w_l Z_l$.

2. After the production locations are chosen, the firm learns about the quality of its plants. It receives a vector of location-specific productivity shifters, $\epsilon$. Together with the core productivity, the vector of productivity shifters determines the productivity of the plants. The product-location-specific productivity is a random variable. The firm decides for each of its products from where to serve each market and selects product-market-specific prices.

The production technology has constant marginal costs inversely proportional to productivity and transforms units of labor into goods. For each of its products, $\upsilon$, firm $\omega$ draws a location-specific productivity from a Fréchet distribution. Let $\upsilon_j$ denote the productivity level in country $j$ for product $\upsilon$.

$$Pr(\upsilon_j \leq x) = \exp\left(-\phi\epsilon_j x^{-\theta}\right)$$

The parameter $\theta$ characterizes the dispersion of the product-location specific productivity shocks.[9] The product of the core productivity level and plant-specific productivity shifter, $\phi\epsilon_j$, determine how good the productivity draws in the plant in country $j$ are. Larger values of $\phi\epsilon_j$ imply better productivity distributions.[10] All firms from country $i$ may have lower productivity in country $l$, which is captured by an iceberg loss in production, $\gamma_{il}$. Trade costs to ship goods from country $l$ to $m$ are of the iceberg type and denoted by $\tau_{lm}$. For simplicity I assume there are no fixed costs to exporting.[11] Consequently, every product is sold to every market.

The costs to serve market $m$ from country $l$ are also Fréchet distributed:

$$Pr(\frac{\gamma_{il} w_l \tau_{lm}}{\upsilon_l} \leq c) = 1 - \exp\left(-(\gamma_{il} w_l \tau_{lm})^{-\theta} \phi\epsilon_l c^{\theta}\right)$$

The product-level costs with which a firm from country $i$, with core productivity parameter $\phi$, and a vector of location-specific productivity shifters $\epsilon$, that selected vector $Z$, will serve market $m$ are distributed according to

[9] The dispersion of the product-location specific productivity shocks is decreasing in $\theta$.

[10] The reader familiar with Eaton and Kortum (2002) may recognize the similarity between the country-specific parameter $T_j$ in their paper with the firm-country-specific parameter $\phi\epsilon_j$ in this paper.

[11] Fixed costs of exporting (on the firm level) could be incorporated in a similar way as in Eaton, Kortum, and Kramarz (2011).

$$G_m(c|i,\phi,Z,\epsilon) = 1 - \exp\left(-\sum_{k:Z_k=1} (\gamma_{ik} w_k \tau_{km})^{-\theta} \phi \epsilon_k c^\theta\right). \tag{6}$$

As is common with CES preferences, monopolistic competition, and a continuum of firms, the firm will charge for every good a constant mark-up over marginal cost, $c$, to deliver the good to the respective market.

$$p = \frac{\sigma}{\sigma - 1} c \tag{7}$$

Using the optimal pricing rule, (7), the distribution of product-level costs, (6), and (3), we can write the firm-level price index, $p_m(i,\phi,Z,\epsilon)$, which characterizes the product-level prices that firm $(i,\phi,Z,\epsilon)$ charges in market $m$, as

$$p_m(i,\phi,Z,\epsilon) = \kappa^{\frac{1}{1-\sigma}} \phi^{-1/\theta} \left(\sum_{k:Z_k=1} (\gamma_{ik} w_k \tau_{km})^{-\theta} \epsilon_k\right)^{-1/\theta}, \tag{8}$$

where $\kappa = \Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}$ is a constant.[12] For technical reasons I impose $\theta > \max(\sigma - 1, 1)$. The total sales of firm $(i,\phi,Z,\epsilon)$ in market $m$ are

$$s_m(i,\phi,Z,\epsilon) = p_m(i,\phi,Z,\epsilon)^{1-\sigma} \frac{Y_m}{P_m^{1-\sigma}}. \tag{9}$$

This expression is quite intuitive. The total sales to market $m$ rise in the core productivity level of the firm. Furthermore, the firm benefits particularly from having a plant in a country $k$ which has low variable costs to supply market $m$ (low $\gamma_{ik} w_k \tau_{km}$) and a large plant-wide productivity shifter (large $\epsilon_k$).

Due to constant returns to scale in the variable production technology, a firm will simply choose for each variety the location with the lowest unit cost to serve a market. We can write the share of products for which the plant in country $l$ is selected to serve country $m$ given location vector $Z$ and location-specific productivity shifters $\epsilon$ as

$$\mu_{lm}(i,\phi,Z,\epsilon) = \Pr\left(\underset{j:Z_j=1}{\operatorname{argmin}} \frac{\gamma_{ij} w_j \tau_{jm}}{\nu_j} = l\right) = \begin{cases} \frac{(\gamma_{il} w_l \tau_{lm})^{-\theta} \epsilon_l}{\sum_{k:Z_k=1} (\gamma_{ik} w_k \tau_{km})^{-\theta} \epsilon_k} & \text{if } Z_l = 1 \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

The share of goods that a firm ships from country $l$ to country $m$ is large if the plant in country $l$ has particularly low costs to serve market $m$ relative to all the other plants the firm has. The cost at which a firm actually supplies market $m$ from location $l$, $Z_l = 1$, also has the distribution $G_m(c|i,\phi,Z,\epsilon)$. Consequently

[12] This step is analogous to the calculation of the *overall* price index in Eaton and Kortum (2002) and uses the moment generating function for Fréchet distributed random variables. The calculation is valid under the restriction that $\theta > \sigma - 1$.

$\mu_{lm}(i, \phi, Z, \epsilon)$ equals not only the share of products that a firm with location vector $Z$ gets from location $l$ for market $m$, but also the corresponding expenditure share. Therefore the sales from location $l$ to market $m$ are

$$s_{lm}(i, \phi, Z, \epsilon) = s_m(i, \phi, Z, \epsilon)\mu_{lm}(i, \phi, Z, \epsilon). \tag{11}$$

The firm-level sales to market $m$ increase as additional production locations are added to the vector of existing locations. However, there is a cannibalization effect across production locations. A firm that adds a production location decreases the sales from the other locations. These findings are expressed formally in Proposition 1.

**Proposition 1.** *Under $\sigma > 1$ and $\theta > \sigma - 1$, let $Z^1 > Z^2$. Then (i) $s_m(i, \phi, Z^1, \epsilon) > s_m(i, \phi, Z^2, \epsilon)$, and (ii) $s_{lm}(i, \phi, Z^1, \epsilon) < s_{lm}(i, \phi, Z^2, \epsilon)$ if $Z_l^2 = 1$.*

*Proof.* Part (i) follows from substituting equation (8) into (9) and noting that $p_m(i, \phi, Z, \epsilon)$ is increasing in $Z$ since $\sigma > 1$. Part (ii) follows from substituting equations (10), (9) and (8) into (11). The denominator is increasing in $Z$ since $\theta > \sigma - 1$. ■

Next, I proceed to study the optimal choice of the location vector, $Z$.

The expected variable profits from vector $Z$ are simply the sum of the expected sales to all markets from all locations contained in the vector times the proportion of sales that represent variable profits.

$$E_\epsilon(\pi(i, \phi, Z, \epsilon)) = \frac{1}{\sigma}\sum_m E_\epsilon(s_m(i, \phi, Z, \epsilon)) \tag{12}$$

At the time the production locations are chosen, the level of fixed costs for each production location are known to the firm. Fixed costs have to be paid in units of labor of the destination country. The total expected profits of vector $Z$ are the expected variable profits minus the fixed cost payments associated with the locations contained in the vector. $f_{ik}$ is the fixed cost component common to all firms from country $i$ to locate in country $k$. The vector of country specific fixed-cost shocks, $\eta$, is specific to each firm. I assume no fixed costs have to be paid for the domestic plant (or have been paid in a firm entry stage that I don't model), i.e., $f_{ii} = 0 \quad \forall i = 1, ..., N$.

$$E_\epsilon(\Pi(i, \phi, Z, \epsilon, \eta)) = E_\epsilon(\pi(i, \phi, Z, \epsilon)) - \sum_{k:Z_k=1} f_{ik}\eta_k w_k \tag{13}$$

Each firm chooses the vector of locations that maximizes its expected profits. I write the vector of locations that maximizes the expected profits as

$$Z(i, \phi, \eta) \in \arg\max_{Z \in \mathcal{Z}^i} E_\epsilon(\Pi(i, \phi, Z, \epsilon, \eta)) \tag{14}$$

As long as $f_{ik} > 0$ for $i \neq k$ and the country-specific fixed cost shocks vector $\eta$ is drawn from a continuous distribution (the draws are independent across countries), the set of fixed cost shock vectors for which the firm is indifferent between two or more location vectors has measure zero.

## 2.3 Aggregation

The share of firms from country $i$ with core productivity $\phi$ that chooses location vector $Z$ is

$$\rho_Z^{i,\phi} = \int_\eta \mathbb{1}\left[Z = Z(i,\phi,\eta)\right] dF(\eta). \tag{15}$$

The sales of firms from country $i$ produced in location $l$ and shipped to market $m$ are

$$X_{ilm} = M_i \int_\phi \sum_{Z' \in \mathcal{Z}^i} \rho_{Z'}^{i,\phi} E_\epsilon(s_{lm}(i,\phi,Z',\epsilon))dG(\phi) \tag{16}$$

Aggregate trade flows from country $l$ to $m$ are simply

$$X_{lm} = \sum_i X_{ilm} \tag{17}$$

The consumer price index in market $m$ is

$$P_m = \left[\sum_i M_i \int_\phi \sum_{Z' \in \mathcal{Z}^i} \rho_{Z'}^{i,\phi} E_\epsilon(p_m(i,\phi,Z',\epsilon)^{1-\sigma})dG(\phi)\right]^{1/(1-\sigma)} \tag{18}$$

Under strictly positive wages, the labor market clearing condition holds if and only if the aggregate labor income received by workers in a country equals the total labor cost paid by firms from all countries to workers in this country. I define the set of location vectors that includes a location in country $k$ as $\Delta_k^i = \{Z \in \mathcal{Z}^i \mid Z_k = 1\}$. Labor is used in production activity and to build facilities by foreign companies.

$$w_k L_k = \frac{\sigma - 1}{\sigma} \sum_m X_{km} + \sum_{i \neq k} M_i \int_\phi \int_\eta \sum_{Z \in \Delta_k^i} \mathbb{1}\left[Z = Z(i,\phi,\eta)\right] f_{ik}\eta_k w_k dF(\eta)dG(\phi) \tag{19}$$

I assume the representative household owns the domestic firms. The aggregate income in country $m$ is then the sum of the labor payments and the profits by firms that originated in country $m$.

$$Y_m = w_m L_m + M_m \int_\phi \int_\eta \sum_{Z \in \mathcal{Z}^m} \mathbb{1}\left[Z = Z(i,\phi,\eta)\right] E_\epsilon(\Pi | i,\phi,Z,\epsilon,\eta)dF(\eta)dG(\phi) \tag{20}$$

Finally, current account balance implies that

$$\sum_l X_{lm} = Y_m \tag{21}$$

Note that it is possible that a country runs a trade deficit, which is financed by the profits that multinational firms of this country make abroad.

### 2.4 Equilibrium

I can now define the global production equilibrium.

Given $\tau_{ij}, \gamma_{ij}, f_{ij}, M_i, F(\eta), G(\phi), R(\epsilon), \mathcal{Z}^i, \forall i, j = 1, ..., N$, a global production equilibrium is a set of wages, $w_i$, price indices, $P_i$, incomes, $Y_i$, allocations for the representative consumer, $q(\omega, \upsilon)$, prices, $p_m(i, \phi, Z, \epsilon)$, and location choices, $Z(i, \phi, \eta)$, for the firm, such that

(i) equation (2) is the solution of the consumer's optimization problem.

(ii) $p_m(i, \phi, Z, \epsilon)$ and $Z(i, \phi, \eta)$ solve the firm's profit maximization problem.

(iii) $P_i$ satisfies equation (18).

(iv) The labor market clearing condition, (19), holds.

(v) $Y_m$ is given by equation (20).

## 3 Estimation of fixed and variable production costs

This section provides estimates for the fixed and variable production costs of German multinationals. Those estimates will be useful for two different purposes. First, they are crucial in determining the key driver of 'home bias in production' for German multinationals. Second, we can use these estimates in the following section in which we calibrate the model to data of multiple countries and conduct welfare analysis. By itself, this section aims to answer the following questions: What are the sources of home bias in production by multinational firms? Are large fixed costs to set up foreign affiliates (increasing returns) the key driver or do multinationals face lower production costs in the home country? Removing fixed cost and production cost differences separately in counterfactual analysis can inform us about their importance.

I estimate the parameters that characterize the distribution of fixed costs, the distribution of core productivity levels of the multinationall firms, the distribution of firm-location-specific productivity shifters, and the variable production costs that German multinationals face in every country. The estimated parameters maximize the likelihood of the observed data. The likelihood function consists for each firm of the probability of its chosen location string and the density of the plant-specific productivity shifters. The estimation controls for unobserved heterogeneity in the core productivity level of the firms and heterogeneity in the fixed cost draws.

I first describe the data and document home bias in production for multinational firms. I then move on to describe the estimation in more detail and discuss the results.

### 3.1 Data description

For this section I use firm level data on German multinational firms in the manufacturing sector. By law, German resident investors are subject to report on the activities of foreign affiliates if the affiliate has a balance sheet total above 3 million Euro and the investor has a share of voting rights of 10 percent or more. The Microdatabase Direct Investment (MiDi) is maintained by the German Bundesbank.[13] I use data for the year 2005 and keep affiliates who are in the manufacturing sector that are majority owned by a parent firm in the manufacturing sector. The literature has pointed out that multinational activity between European and North American countries is driven mostly by market access considerations as opposed to vertical FDI that aims to benefit from vast differences in capital labor ratios. As my model features horizontal FDI, I focus on German multinationals' activities in twelve developed Western European and North American countries.[14] I take the vector of locations in which a multinational owns an affiliate (including the home country) as the corresponding data analogue to the vector of production plants in the model. I observe for each affiliate the total sales as well as the total sales by the parent company.[15]

After applying the selection criteria above, I am left with 665 firms and 1,711 positive firm-country output observations. The United States and France are the most popular destination countries for German multinational firms. Table 8 describes the activities on the country level. Most multinationals concentrate their production in very few countries. The average number of production locations (including the home country) is 2.57. Further, the fraction of the production of multinationals that occurs abroad is small relative to the fraction of foreign economies' production to the global economy's production. I call this phenomena 'home bias in production'. On average across all German multinationals, the share of foreign production in total output is .29. Table 9 displays that the share of foreign production in total output is rising in the number of foreign affiliates. However, even for firms with more than six production locations the average output share at home is around 50 percent. Suppose a firm's output in country $k$ was proportional to the value of gross production in country $k$. This would result in an average share of foreign output to global output controlling for the vector

[13] Other research uses of the database include Muendler and Becker (2010) who study the margins of multinational labor substitution for multinational firms and Buch, Kleinert, Lipponer, and Toubal (2005) who characterize the patterns of German firms' multinational activities.

[14] These countries are Austria, Belgium, Canada, Switzerland, Germany, Spain, France, United Kingdom, Ireland, Italy, Netherlands, and the United States.

[15] I consolidate multiple affiliates in the same country by the same parent company into one entity.

of locations the firm is active in of 0.44.[16] As this is larger than the actual foreign output share of firms, this suggests that beyond fixed costs, differences in variable production costs drive 'home bias in production'.

I use data on gross production and bilateral trade flows from the OECD STAN database to calculate country specific manufacturing absorption, and use estimates from an auxiliary estimation of a standard gravity pure trade model as proxies for bilateral trade costs between countries and price indexes.

## 3.2 Estimation

The estimation uses data on both the output at every production location and the vector of production locations that was chosen by the multinational. Additionally data on manufacturing absorption, and proxies for price indexes and trade costs are used to measure local and surrounding market potential. I control for unobserved heterogeneity in the core productivities across firms. Let $\tilde{f_{t,k}} = f_{ik}\eta_{t,k}w_k$ denote the value of the fixed costs that firm $t$ has to pay to erect a production facility in country $k$. Let $\omega_k = w_k\gamma_{ik}$ denote the unit input costs in country $k$. As the country of origin, $i$, always represents Germany here, I drop it from the notation in this section. I add a subscript $t$ to the variables which are firm-specific. I assume that the fixed cost that a firm has to pay to start production in country $k$, $\tilde{f_{t,k}}$, is drawn from a log-normal distribution with mean $\mu_{\tilde{f}}$ and standard deviation $\sigma_{\tilde{f}}$ independently across countries and firms. I set the fixed costs in Germany to zero and normalize the unit input costs in Germany to one.

Using the new notation - with firm subscripts, $\tilde{f_{t,k}} = f_{ik}\eta_{t,k}w_k$, $\omega_k = w_k\gamma_{ik}$ - and equations (12) and (13) from the model, the expected profits from selecting location vector $Z$ for firm $t$ with core productivity, $\phi_t$ and fixed cost draws $\tilde{f}_t$ are:

$$E_\epsilon(\Pi|\phi_t, Z, \epsilon, \tilde{f}_t; \sigma_\epsilon, \omega) = \frac{1}{\sigma}\kappa\phi_t^{(\sigma-1)/\theta}\sum_m \int_\epsilon \frac{Y_m}{P_m^{1-\sigma}}\left(\sum_{k:Z_k=1}(\omega_k\tau_{km})^{-\theta}\epsilon_k\right)^{(\sigma-1)/\theta} dH(\epsilon \mid \sigma_\epsilon) - \sum_{k:Z_k=1}\tilde{f_{t,k}} \quad (22)$$

The first term represents expected variable profits from having a production facility in the countries contained in the location vector and the second term represents the fixed costs that the firm would have to pay. Recall that the level of fixed costs is known at the time the firm makes its decision, but the firm only learns how productive these are after selecting its plants. I assume the location-specific productivity shifter $\epsilon$ is drawn from a log-normal distribution, $\log\mathcal{N}(0, \sigma_\epsilon)$, independently across countries. Following equation (15) from the model, we can then write the probability that a firm with core productivity level $\phi_t$ selects location vector $Z_t$

[16] Specifically, I calculate for each firm with location vector $Z$, $\frac{\sum_{k\neq i:Z_k=1} y_k}{\sum_{k:Z_k=1} y_k}$, where $y_k$ denotes gross production in manufacturing in country $k$ and $i$ denotes the country of origin of the firm (here Germany). The average of this measure across firms is 0.44 as opposed to 0.29 for the average foreign output share of the firms.

as

$$Pr(Z = Z_t \mid \phi_t; \omega, \sigma_\epsilon, \mu_{\tilde{f}}, \sigma_{\tilde{f}}) = \int_{\tilde{f}} \mathbb{1}\{E_\epsilon(\Pi|\phi_t, Z, \epsilon, \tilde{f}; \sigma_\epsilon, \omega) \geq E_\epsilon(\Pi|\phi_t, Z', \epsilon, \tilde{f}; \sigma_\epsilon, \omega) \quad \forall Z'\} dF(\tilde{f} \mid \mu_{\tilde{f}}, \sigma_{\tilde{f}}). \tag{23}$$

The decision of the location vector $Z$ depends on the firm's core productivity, $\phi_t$, and the parameters $(\omega, \sigma_\epsilon, \mu_{\tilde{f}}, \sigma_{\tilde{f}})$ which I am going to estimate.

Aside from the information about the location vector that the multinational chose, we know about its total output in each country it is active in. We can learn about the productivity of the multinational in each location from the output of each affiliate (and the output at home). The actual productivity in country $l$ is the product of the core productivity level $\phi_t$ and the firm-country specific productivity shifter, $\epsilon_{t,l}$. I denote it by $\psi_{t,l} = \phi_t \epsilon_{t,l}$. Let $r_{t,l}(\omega, Z_t, \psi_t) = \sum_m s_{lm}(i_t, \phi_t, Z_t, \epsilon_t)$ denote the total revenue from sales to all countries of firm $t$ in country $l$. Plugging in equations (10), (8), (9), and (11) we get for the revenue of firm $t$ in country $l$ the following equation:

$$r_{t,l}(\omega, Z_t, \psi_t) = \kappa \sum_m \frac{Y_m}{P_m^{1-\sigma}} \frac{(\omega_l \tau_{lm})^{-\theta} \psi_{t,l}}{\left( \sum_{k: Z_{t,k}=1} (\omega_k \tau_{km})^{-\theta} \psi_{t,k} \right)^{\left(\frac{\theta+1-\sigma}{\theta}\right)}}. \tag{24}$$

We have such an equation for every location in which firm $t$ has a production location. Let $r_t$ denote the vector of revenues of firm $t$ in its production locations. Knowing the sales of a firm in each of its locations and all other parameters allows us to pin down exactly its productivity level, $\psi_k = \phi \epsilon_k$ in each of its locations $k$. Proposition 2 states that given all other parameters, the solution to this system of equations is unique (the proof is in the appendix).

**Proposition 2.** *Let $K$ denote the number of countries in which firm $t$ has a plant. Let $r : \mathbb{R}^K_{++} \times \{0,1\}^N \times \Psi \rightarrow \mathbb{R}^K_{++}$ be the stacked vector of revenues as defined in equation (24). $\Psi = [\psi_{min}, \psi_{max}]^K$ where $\psi_{min} > 0$ and $\psi_{min} < \psi_{max} < \infty$. Then for any triple $\{r_t, \omega, Z\}$, the vector $\psi$ that solves $r_t - r(\omega, Z, \psi) = 0$ is unique.*

The estimation controls for unobserved heterogeneity in the core productivity levels of the firms. I assume the core productivity levels of the German multinationals is lognormally distributed, $\log \mathcal{N}(\mu_\phi, \sigma_\phi)$.

Let $t$ denote the firm, $Z_t$ the location vector chosen by firm $t$, and $r_{t,l}$ the revenue from sales to all countries from the affiliate in country $l$. Let $h(\cdot \mid \sigma_\epsilon)$ denote the univariate lognormal density which in log scale has mean zero and standard deviation $\sigma_\epsilon$. The likelihood function can be written as:

$$L(\omega,\psi,\sigma_\epsilon,\mu_{\tilde{f}},\sigma_{\tilde{f}},\mu_\phi,\sigma_\phi)=\prod_{t=1}^{T}\int_\phi Pr(Z=Z_t\mid\phi;\omega,\sigma_\epsilon,\mu_{\tilde{f}},\sigma_{\tilde{f}})\prod_{l:Z_{t,l}=1}h(\frac{\psi_{t,l}(\omega,\sigma_\epsilon)}{\phi}\mid\sigma_\epsilon)dG(\phi\mid\mu_\phi,\sigma_\phi) \quad (25)$$

The fact that we learn about the firm's productivity level in country $k$ - given the current parameter guess - from a system of equations suggests a constrained maximum likelihood estimation procedure should be used. The estimated vector of unit input costs, $\hat{\omega}$, the vectors that characterize the destination country specific distributions of fixed costs, $\hat{\mu}_{\tilde{f}},\hat{\sigma}_{\tilde{f}}$, the parameters for the core productivity distribution, $\hat{\mu_\phi},\hat{\sigma_\phi}$, and the parameter that characterizes the firm-country level productivity shocks, $\hat{\sigma_\epsilon}$, together with the firm-country specific productivity level vector, $\hat{\psi}$, solve the following problem:

$$\max_{\omega,\psi,\sigma_\epsilon,\mu_{\tilde{f}},\sigma_{\tilde{f}},\mu_\phi,\sigma_\phi} \quad \log L(\omega,\psi,\sigma_\epsilon,\mu_{\tilde{f}},\sigma_{\tilde{f}},\mu_\phi,\sigma_\phi)$$

$$\text{subject to:} \qquad r_{t,l}(\omega,Z_t,\psi_t)=\kappa\sum_m\frac{Y_m}{P_m^{1-\sigma}}\frac{(\omega_l\tau_{lm})^{-\theta}\psi_{t,l}}{\left(\sum_{k:Z_{t,k}=1}(\omega_k\tau_{km})^{-\theta}\psi_{t,k}\right)^{\left(\frac{\theta+1-\sigma}{\theta}\right)}} \quad (26)$$

$$\forall\ t\in\{1,...T\},\ l\in\{1,...N\}\text{ such that }Z_{t,l}=1.$$

I use a logit-smoothed accept-reject simulator to evaluate the probability of location choice described in (23).[17] The estimation is an implementation of the Mathematical Programming with Equilibrium Constraints (MPEC) procedure proposed by Su and Judd (forthcoming). They show that the estimator is equivalent to a nested fixed-point estimator in which the inner loop solves for the firm-country specific productivity levels, and the outer loop searches over parameters to maximize the likelihood. The estimator therefore inherits all the statistical properties of a fixed-point estimator. It is consistent and asymptotically normal as the number of firms tends to infinity and the number of simulation points to evaluate the integrals rises proportional to the number of firms.[18] As there are 1,711 positive firm-country output observations, this is a problem with 1,747 variables (36 structural parameters and 1,711 country-firm productivity levels) and 1,711 equality constraints. I describe the details of the computational procedure in the appendix [to be added].

## 3.3 Parameter Estimates

I estimate unit input costs of German manufacturing firms in other countries (relative to the costs at home), the distribution of fixed costs for each country, and a distribution of productivity levels across firms. I set the

[17]See Train (2009), Chapter 5, for an excellent description of this and other methods.

[18]As the integrals are evaluated numerically in a finite sample with finite simulation draws the Simulated Maximum Likelihood Estimator is necessarily biased (after taking logarithms of the Likelihood function). I do a Monte-Carlo study of my estimation procedure and find that the bias is very small in practice for this problem.

value of the elasticity of substitution between products, $\sigma$, to six. This implies a reasonable mark-up of 20 percent above marginal costs. The estimates are robust to various parameters for the dispersion parameter, $\theta$ of the distribution of the country-firm specific productivity shifters. I use a benchmark value of seven for the dispersion parameter ($\theta = 6$ and $\theta = 9$ give very similar results).[19]

Table 1 displays the parameter estimates. I find that the variable costs of production (unit input costs) are systematically smaller in the domestic country than in foreign countries (unit input costs in Germany are normalized to one). The smallest difference in unit input costs is with respect to Austria, in which German multinationals face only around six percent larger variable production costs than at home. Within Western European countries, the production costs for German multinationals are largest in Italy and the United Kingdom (33 percent higher than in Germany). The production costs in the United States are around 40 percent higher than at home. The differences in production costs may reflect differences in the wage levels and efficiency losses that occur by producing outside your home country. These efficiency losses may occur because of communication costs, information frictions, or shipments of intermediate products.

We can give the fixed costs a value interpretation as we observe the firms' output in Euro and under the assumption of CES preferences and monopolistic competition, variable profits are proportional to output. Identification of fixed costs comes from observing the actual choice of production locations and variable profits together with the counterfactual scenarios of how variable profits would change if the firm altered its vector of production locations. Table 1 displays the estimates for the country-specific fixed costs distribution parameters. Using these estimates, I calculate the probability with which a German multinational has fixed entry costs to produce in the respective country that are lower than 5 million Euro. The probabilities are presented in Table 2. The probability of a fixed cost to set up a production facility in a foreign country for less than 5 million Euro is the largest in the United States and France (around 25 percent). In Ireland, however, the probability of a low fixed cost draw is only around 3 percent. The second column in Table 2 shows the mean fixed costs that firms who set up a production location paid in the respective countries. For most countries the estimated mean fixed cost is between 4-6 million Euro. The fixed cost is estimated to be larger in Canada (8 million) and Belgium (13 million Euro). The larger fixed cost estimates for these countries are sensible in the light of Table 8. Belgium has almost the same geographic location as the Netherlands and a similar local and surrounding market potential. While the number of German firms that have production location in these countries is about the same, the output of plants in Belgium is much larger. This is reflected in the estimation by a lower variable production cost in Belgium and a larger level of fixed cost to keep the number of entrants at the same level

[19] Ideally I would estimate $\frac{\theta}{\sigma-1}$ from firm-product bilateral export data or sales data in a particular country. The distribution of costs to serve market $m$ in (6) together with the optimal pricing rule and the demand function imply that the product-level sales of a particular firm are distributed Fréchet with dispersion parameter $\frac{\theta}{\sigma-1}$. Data for the entire manufacturing sector would be most appropriate to use as this is my selection criteria for the multinationals and trade data. When using car model sales data in five European countries available from Goldberg and Verboven (2001) I find an estimate of $\widehat{\frac{\theta}{\sigma-1}} = 1.02$.

with Netherlands. Similarly, only a small number of firms has a plant in Canada, but those tend to have a very large output. The calculation of the mean fixed cost conditional on having established a plant in the country is described in Appendix C.

The estimates are based on annual profits. I abstracted away from dynamic considerations. The fixed costs can be interpreted as annualized value of sunk costs to establish a foreign affiliate.

### 3.4 Decomposing the sources of home bias in production

The parameter estimates above demonstrate both significant fixed costs to starting production in a foreign country and higher variable production costs abroad. Both contribute to home bias in production. If the unit input costs in the foreign countries were the same as in Germany and there were no fixed costs for setting up foreign plants, every firm had a plant in each country and the average foreign output share across firms would be around 0.88.[20] In the data (and estimated model) the average foreign output share is only around 0.29. If unit input costs were equalized across countries and fixed costs were kept at their estimated level, firms would re-optimize their production locations and output decisions such that the foreign output share would be around 0.62. If instead fixed costs were eliminated (and unit input costs held at their estimated level), the average foreign output share rises even further to around 0.69. Overall, I find that both fixed costs and differences in unit input costs are significantly contributing to home bias in production. Both factors have a similar quantitative effect. The difference in the foreign output shares (0.62 and 0.69) is significant at a 10 percent level.[21]

[20]The difference the share of foreign in global gross output (85 percent) mentioned in the introduction arises from the possibility of export platform sales and that in the data not every firm is active in every country.

[21](The standard error of the difference of the foreign production share between "No fixed costs" and "Same variable costs" is 0.041)

Table 1: Maximum Likelihood Estimates

| | | Unit input costs $\omega$ | Fixed costs $\mu_{\tilde{f}}$ |
|---|---|---|---|
| Country | | | |
| *Austria* | | 1.074 | 4.674 |
| | | (0.230) | (0.173) |
| *Belgium* | | 1.149 | 5.953 |
| | | (0.205) | (0.230) |
| *Canada* | | 1.321 | 5.468 |
| | | (0.203) | (0.205) |
| *Switzerland* | | 1.235 | 5.170 |
| | | (0.157) | (0.203) |
| *Spain* | | 1.216 | 4.138 |
| | | (0.135) | (0.157) |
| *France* | | 1.212 | 3.493 |
| | | (0.136) | (0.135) |
| *United Kingdom* | | 1.327 | 4.061 |
| | | (0.439) | (0.136) |
| *Ireland* | | 1.119 | 7.083 |
| | | (0.137) | (0.439) |
| *Italy* | | 1.328 | 4.268 |
| | | (0.277) | (0.137) |
| *Netherlands* | | 1.183 | 5.943 |
| | | (0.122) | (0.277) |
| *United States* | | 1.403 | 3.529 |
| | | (0.027) | (0.122) |
| S.d. log fixed cost, $\sigma_{\tilde{f}}$ | 2.9933 | | |
| | (0.125) | | |
| Mean log core productivity, $\mu_G$ | 0.3814 | | |
| | (0.011) | | |
| S.d. log core productivity, $\sigma_G$ | 0.2369 | | |
| | (0.007) | | |
| S.d. log productivity shock, $\sigma_\epsilon$ | 0.1704 | | |
| | (0.003) | | |
| Log-Likelihood | -2.68E+003 | | |
| Number of firms, $T$ | 665 | | |

*Notes:* Unit input costs in Germany are normalized to one. Standard errors in parentheses.

Table 2: Fixed cost by country

| Country | Probability of fixed cost draw less than 5 million Euro | Mean fixed cost of firms who set up a plant in the respective country in million Euro |
|---|---|---|
| Austria | 0.153 | 5.930 |
| | (0.027) | (1.582) |
| Belgium | 0.073 | 13.225 |
| | (0.020) | (3.908) |
| Canada | 0.099 | 8.495 |
| | (0.027) | (2.993) |
| Switzerland | 0.117 | 4.819 |
| | (0.027) | (2.057) |
| Spain | 0.199 | 5.127 |
| | (0.030) | (1.921) |
| France | 0.265 | 5.929 |
| | (0.025) | (1.279) |
| United Kingdom | 0.206 | 5.807 |
| | (0.025) | (1.449) |
| Ireland | 0.034 | 4.449 |
| | (0.012) | (1.908) |
| Italy | 0.187 | 5.395 |
| | (0.024) | (1.392) |
| Netherlands | 0.074 | 5.373 |
| | (0.022) | (2.434) |
| United States | 0.261 | 5.184 |
| | (0.025) | (1.132) |

*Notes:* Standard errors in parentheses.

Table 3: Average share of foreign production in the output of German multinationals

| Data | Model | Same unit input costs as in Germany | No fixed costs | No fixed costs and same unit input costs as in Germany |
|---|---|---|---|---|
| 0.288 | 0.291 | 0.626 | 0.695 | 0.879 |
| | (0.067) | (0.050) | (0.031) | (0.004) |

*Notes:* Trade costs, and price indices are hold fixed. Standard errors in parentheses.

## 4 Calibration and welfare analysis

In this section I calibrate trade costs, variable foreign production costs and fixed costs to set up foreign affiliates to data on bilateral trade shares, bilateral MP shares, and the estimates of the country-specific variable production costs of German multinationals from the previous section. The estimates on fixed and variable production costs for German multinationals from the previous section enable me to include both variable foreign production frictions and fixed costs in the analysis. I solve for the endogenous relative wages and price indices in every country.

I address the following questions: Do fixed costs to set up foreign plants also help explain the aggregate data?[22] Does multinational production alter the conventional estimates of the gains from trade? What is the role of multinational firms in transmitting technological improvements to foreign countries? Finally, what are the potential effects from an EU-Canada free trade and investment agreement on related and unrelated parties?

### 4.1 Data

The analysis incorporates the same 12 Western European and North American countries as the previous section. Data on multinational production comes from Ramondo, Rodriguez-Clare, and Tintelnot (in process).[23] Gross manufacturing production and bilateral trade data comes from OECD STAN. With this data I construct MP and bilateral trade shares as described in detail in the appendix; the model equivalents are equations (28) and (27). Data on labor endowments come from the Penn World Tables. Data on educational attainment levels by country are from Barro and Lee (2010). Data on trade and MP are averages across the years 1996 to 2001. Data on population and educational attainment are for the year 2000.

### 4.2 Calibration

I fix some parameters, while I calibrate the others. The fixed parameters are described first. The mass of firms in country $i$, $M_i$, is set proportional to the product of population size and average years of schooling in country $i$. The size of the labor force, $L$, is set proportional to the population. As in the previous section, the value for the dispersion parameter of the product level productivity shock distribution, $\theta$, is set to seven, and the elasticity of substitution, $\sigma$, is fixed to six. Following Chaney (2008), the core productivity levels for all firms are

[22] Ramondo and Rodriguez-Clare (forthcoming) and Arkolakis, Ramondo, Rodriguez-Clare, and Yeaple (2012) recently developed models that feature multinational production with export platform sales without increasing returns in multinational production. I compare my fit with their fit of the export platform sales of US multinationals.

[23] Unlike bilateral trade flow data, data on production activities of multinationals in foreign countries is documented only sporadically. They use available data from UNCTAD, BEA, Bundesbank and other sources on non-financial affiliate sales together with information on M&A from Thomson & Reuters to predict the aggregate total sales of (non-financial) affiliates from country $i$ in country $l$.

drawn from a Pareto distribution.[24] Axtell (2001) estimates that US firm sizes are Pareto distributed with scale parameter $\tilde{\theta_2} = 1.098$. This suggests a shape parameter, $\theta_2$, of the Pareto distribution for the core productivity levels of 5.5.[25] As we are not aiming to explain an individual firm's data in this section, I abstract from the distribution of firm-location specific productivity shifters here ($\epsilon_l = 1 \forall l$). This avoids evaluating numerically large-dimensional integrals without much explanatory power, since only aggregated information is used in this section.

I estimate the parameters that characterize the trade costs between countries $l$ and $m$, $\tau_{lm}$, efficiency losses of foreign production, $\gamma_{il}$, and the fixed costs to set up plants in country $l$ as a firm from country $i$, $f_{il}$. I specify the following functional form for trade and foreign production iceberg costs:

$$\begin{aligned} \tau_{lm} &= \beta^{\tau}_{const}(dist_{lm})^{\beta^{\tau}_{dist}}(\beta^{\tau}_{contig})^{contig_{lm}}(\beta^{\tau}_{lang})^{language_{lm}} \quad \text{for } l \neq m \\ \gamma_{il} &= \beta^{\gamma}_{const}(dist_{il})^{\beta^{\gamma}_{dist}}(\beta^{\gamma}_{contig})^{contig_{il}}(\beta^{\gamma}_{lang})^{language_{il}} \quad \text{for } i \neq l \end{aligned}$$

Domestic production iceberg costs and trade costs are set to one. Fixed costs for the domestic production location are set to zero. For all $l \neq i$, the fixed costs to set up a plant in location $l$ for a firm from $i$ (in units of labor in the destination country) are

$$f_{il} = \beta^{f}_{const}(dist_{il})^{\beta^{f}_{dist}}(\beta^{f}_{contig})^{contig_{il}}(\beta^{f}_{lang})^{language_{il}}\zeta_l \quad \text{for } i \neq l.$$

The parameter $\zeta_l$ is a random variable drawn independently across firms and locations from a log-normal distribution with $\log \zeta$ distributed $N(0, \beta^f_\sigma)$.

The model delivers predictions for MP and trade shares which can be used as moments to calibrate the parameters. The share of expenditures by consumers from country $m$ that is spent on goods produced in country $l$ ('trade-share') is

$$\xi_{lm} = \frac{X_{lm}}{Y_m} \tag{27}$$

and the share of output produced by firms from country $i$ in country $l$ ('MP-share') is

[24]In the previous section with German multinationals' firm-level data, I assumed that the subset of firms who are multinationals can be characterized by a lognormal distribution with two free parameters. Here, I assume that across all active firms (not just multinationals), the core productivity is distributed Pareto (with one parameter). As the decision to set up a location is interdependent across locations, no simple cutoff rule applies.

[25]In the restricted version of my model with only a single production location for each firm (which is true for most firms in practice), the firm size distribution inherits the distribution of the core productivity levels and therefore will be Pareto distributed with shape parameter $\tilde{\theta_2} = \frac{\theta_2}{\sigma-1}$.

$$\kappa_{il} = \frac{\sum_m X_{ilm}}{\sum_m X_{lm}}. \tag{28}$$

As an additional set of moments I include the relative unit production costs of German firms in various countries which were estimated in section 3. These are driven both by the foreign efficiency losses, $\gamma$, and the endogenous relative wages, $w$. Relative variable production costs for German ($j$) firms in country $l$, are $\frac{\omega_l}{\omega_j} = \frac{w_l \gamma_{jl}}{w_j}$. The three sets of moments are stacked into the following vector:

$$d(\beta, w, A) = \begin{bmatrix} \xi(\beta, w, A) - \xi \\ \kappa(\beta, w, A) - \kappa \\ \frac{\omega(\beta,w,A)}{w_j} - \frac{\omega}{\omega_j} \end{bmatrix}$$

$d(\beta)$ is a $300 \times 1$ vector in which each element characterizes the distance between the respective model outcome (given the parameter vector $\beta$) and the outcome in the data.

The calibration's objective is to minimize the sum of the squared differences between the model outcomes and the data targets for these outcomes. As we vary the parameter vector $\beta$, the equilibrium values of wages, profits (income), and price indices change. Note that in order for firms to choose their optimal policy, simply the equilibrium wages and the market potential $A_m = \frac{Y_m}{P_m^{1-\sigma}}$ need to be known. Let $A_m(\beta, A, w)$ denote the market potential in country $m$ that comes out of the policy functions of the firms and equations (20) and (18). Searching for an equilbrium we seek a vector of market potentials $A$ and wages $w$ such that $A_m(\beta, A, w) = A_m \quad \forall m = 1, ..., N$ and the labor market clearing condition, (19), holds. As the in the previous section, this suggests a constrained optimization procedure to calibrate the parameters.

Formally, the calibration solves the following constrained optimization problem:

$$\begin{aligned} &\min_{\beta, w, A} d(\beta, w, A)' d(\beta, w, A) \\ &\text{subject to:} \\ &A(\beta, w, A) = A \\ &\text{(19) holds } \forall k = 1, ..N \end{aligned} \tag{29}$$

As only relative wages matter, I normalize one country's wage and drop one labor market clearing condition.

## 4.3 Calibration results

The parameter estimates are displayed in Table 4. For comparison, I also display the calibrated parameters for a pure trade model.[26] The trade costs estimates are very similar, however the distance coefficient is slightly larger and the constant slightly lower in the pure trade model. The model of global production in this paper fits trade flows similarly well to a pure trade model and additionally fits multinational production. The iceberg loss in foreign production, $\gamma$, is relatively invariant to distance between the country of origin of the firm and the country of foreign production. Instead, fixed costs are rising with distance.

Identification of the variable MP cost parameters comes from the moments on variable production costs for German multinational firms in different countries. The identification of the fixed cost parameters comes from the moments on bilateral MP shares. Note the calibration results for the fixed cost parameters imply that the fixed cost is rising in distance between the source and destination country - which wasn't a pattern of the German firm level estimates in the previous section. However, data for many more country pairs is used for this section. The estimates reflect that bilateral MP declines with distance.

Table 4: Calibrated parameters

| | Pure trade model | Global production model |
|---|---|---|
| Trade cost | | |
| constant | 0.722 | 0.777 |
| distance | 0.139 | 0.123 |
| language | 0.922 | 0.928 |
| contiguity | 0.934 | 0.928 |
| Variable MP cost | | |
| constant | | 1.283 |
| distance | | 0.004 |
| language | | 0.962 |
| contiguity | | 0.956 |
| Fixed MP cost | | |
| constant | | 0.077 |
| distance | | 0.091 |
| language | | 1.022 |
| contiguity | | 1.175 |
| dispersion | | 0.302 |
| Norm trade fit | 0.258 | 0.262 |
| Norm MP fit | | 0.158 |

[26] My model collapses to a pure trade model if the fixed cost for a foreign plant is infinite.

The calibration is targeted to fit bilateral trade and MP shares, as well as the relative variable production costs of German multinationals in various countries. The question arises how does the calibrated model perform with respect to moments it didn't try to fit? I use data from the BEA on the export platform share of US multinational firms in all countries other than the US in my estimation, and compare the model's predictions with the actual data. The fit is good and displayed in Figure 2. Notice that existing work on multinational production by Ramondo and Rodriguez-Clare (forthcoming) and Arkolakis, Ramondo, Rodriguez-Clare, and Yeaple (2012) can get close to fitting the export platform share of US multinationals only under special cases (e.g., uncorrelated productivities across countries within the firm in Ramondo and Rodriguez-Clare (forthcoming)). The key difference between this paper and their work is that this paper incorporates fixed costs to establish foreign plants. Fixed costs cause firms to concentrate their production in fewer locations which generates export platform sales.

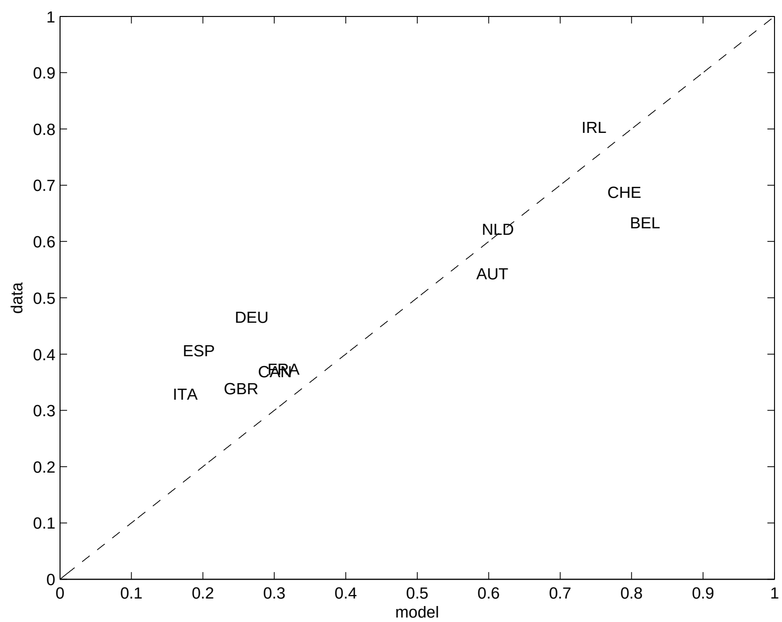


Figure 2: Export platform shares for US multinationals - data and model

## 4.4 Counterfactual experiments

### 4.4.1 Gains from Trade

The workhorse models in multi-country trade analysis, such as Anderson and van Wincoop (2003) and Eaton and Kortum (2002), abstract away from multinational production. How do the gains from trade in these pure trade models differ from the gains from trade in this model with trade and MP?

The gains from trade in this model can be calculated as the change in welfare from the benchmark model to a model with infinite trade costs.[27] Welfare in country $j$ is equal to real income, $\frac{Y_j}{P_j}$. To assess the gains from trade implied by a pure trade model, I take the trade shares from the calibrated global production model and plug them into the welfare formula derived in Arkolakis, Costinot, and Rodriguez-Clare (2012).[28] This is equivalent to calibrating a pure trade model to the predicted trade flows by the 'true' model with trade and MP, and then calculating the gains from trade as the relative change to welfare in autarky. The results are displayed in Table 5.

The results suggest that the gains from trade are slightly larger in a pure trade model than in a model with trade and MP (though the difference is small). As expected, smaller countries benefit more in both models from trade openness than larger countries. While the interactions between trade and MP can be complex, the difference in the estimates of the gains from trade is negligible. This differs from the findings in Ramondo and Rodriguez-Clare (forthcoming) who found for their calibrated model that the gains from trade were systematically larger in a world with MP than in a world without MP. It appears that the difference in the findings is largely driven by the difference in the production structure of the multinational firms between the two models. In their model, the input bundle of a multinational firm abroad is a CES aggregator of the local input bundle in the country of the affiliate and the input country in the home country. Unlike in my model, the availability of trade therefore improves the cost structure of the foreign affiliates in their model considerably.

Table 5: Gains from Trade

| | without MP | with MP |
|---|---|---|
| Austria | 1.207 | 1.193 |
| Belgium | 1.382 | 1.347 |
| Canada | 1.108 | 1.097 |
| Switzerland | 1.342 | 1.318 |
| Germany | 1.068 | 1.060 |
| Spain | 1.053 | 1.049 |
| France | 1.083 | 1.074 |
| United Kingdom | 1.066 | 1.059 |
| Ireland | 1.324 | 1.306 |
| Italy | 1.047 | 1.042 |
| Netherlands | 1.209 | 1.189 |
| United States | 1.012 | 1.011 |

The findings suggest that if one wants to evaluate the gains from trade, the usage of a pure trade model and ignoring multinational production does not affect the results too much. Note, that this neither means that

[27] While the trade with goods is prohibited in this hypothetical world without trade, I allow for the flow of remittances between countries, so that bilateral MP does not necessarily have to be balanced.

[28] The gains from trade for country $j$ can be calculated as $\xi_{jj}^{\frac{1}{1-\sigma}}$. I use $\sigma = 6$ as the trade elasticity.

the gains from multinational production are low nor that for other policy questions multinational production would not matter. In the following two subsections multinational production plays an instrumental role for equilibrium outcomes.

### 4.4.2 Gains from US technology improvement

How do countries benefit from foreign technology improvement? Specifically I ask what happens to welfare in foreign countries if all US firms improve their core productivity level by 20 percent.[29] To make the results comparable to Eaton and Kortum (2002), I divide the welfare gains in foreign countries by the welfare gains in the US. Similarly to them I find that in a pure trade model the percentage gains decay dramatically with distance and size. With multinational production, an additional source of gains for foreign countries arises: multinational firms use the better technology in their plants in foreign countries and crowd out some of the production of less productive domestic firms. Hence the average productivity in foreign countries rises. This effect appears to be strong. Interestingly, in the global production model the welfare gains from a US technology improvement in foreign countries are about an order of magnitude larger than in the pure trade model. Still, Canada as the neighboring country benefits most from US technology improvement as both the costs to ship goods and to transfer technology are rising in distance.

Table 6: Gains from US technology improvement

| | Relative to benchmark | | Relative to US gains | |
|---|---|---|---|---|
| | Pure trade model | Global production model | Pure trade model | Global production model |
| Austria | 1.0009 | 1.0319 | 0.45 | 14.52 |
| Belgium | 1.0005 | 1.0207 | 0.26 | 9.42 |
| Canada | 1.007 | 1.0629 | 3.53 | 28.66 |
| Switzerland | 1.0007 | 1.0204 | 0.37 | 9.30 |
| Germany | 1.0003 | 1.0157 | 0.15 | 7.17 |
| Spain | 1.0005 | 1.0312 | 0.26 | 14.20 |
| France | 1.0003 | 1.0172 | 0.17 | 7.85 |
| United Kingdom | 1.0006 | 1.0301 | 0.32 | 13.70 |
| Ireland | 1.0022 | 1.0459 | 1.12 | 20.93 |
| Italy | 1.0004 | 1.0242 | 0.18 | 11.04 |
| Netherlands | 1.0006 | 1.0286 | 0.32 | 13.03 |
| United States | 1.1987 | 1.2195 | 100.00 | 100.00 |

*Notes:* Counterfactual: Productivity improvement of all firms that originated in the United States by 20 percent. Columns 3 and 4: Welfare gains by country in percent relative to welfare gains in the United States.

In the global production model, the level of technology used in production in a country is endogenous as firms decide about their locations of production. An overall improvement to the the level of technology of

[29]The core productivity level of the firms is Pareto distributed; I multiply the draws for US firms by 1.2.

US firms improves the level of technology used in production in foreign countries. In other words, multinational firms enhance the spread of technology to foreign countries.[30] The gains from foreign technology improvements are dramatically underestimated if multinational production is omitted from the analysis.

The United States also gains more from its firms' technology improvement when multinational production is allowed. US multinational firms can benefit from the relatively cheaper labor in foreign countries and receive larger profits which raises the US consumer's income. Note that the US welfare gains exceed 20 percent under a unilateral technology improvement for US firms. If all countries had improved their firms' technology by 20 percent, every country's welfare would have simply risen by 20 percent. This implies that while countries benefit from foreign technology improvements that raise the technology frontier, as other countries catch up to a country that had a leadership position its welfare can decline.

### 4.4.3 Potential effects from an EU-Canada free trade and investment agreement

The EU and Canada are currently negotiating a free trade and investment agreement - CETA.[31] What would be the effect of such an agreement on the signatories and the U.S.? My setup is particularly suitable to address this question. As multinational firms tend to concentrate production in just a few locations and serve the rest of the world via export platform sales, investment liberalization agreements may have particularly strong third country effects. Third country effects arise in pure trade models due to terms of trade effects. With multinational production - in addition to terms of trade effects - the firm can directly move its production locations and volume between countries, so the effect on third countries may be stronger as the global bilateral investment cost structure changes. For instance, a European firm may want to have only one plant in North America. As investment barriers to Canada fall, some European investment may be moved from the United States to Canada. Much of these effects would be missed by models that do not take into account export platforms, since without export platforms the firm's decision to put up a plant in a country is independent across countries.

Suppose a deep investment agreement can be reached that lowers both variable and fixed MP costs between the EU countries and Canada by 20 percent. Table 7 displays the difference in the MP-shares before and after the liberalization, as well as the relative change in welfare. The aggregate MP-share of EU countries in Canada would increase from 9 to 32 percent. US firms would react to higher relative Canadian wages and reduce their investment in Canada such that the share of US production in Canada would fall from 21 to 9

[30] The gains from foreign technology improvements may be even larger when spillovers are included. Alfaro and Chen (2012) estimate that around 2/3 of the gains from multinational production arise through technology spillovers.

[31] Comprehensive Economic and Trade Agreement (CETA). Currently discussed measures to remove investment barriers between the EU and Canada include harmonization in taxes and regulation, opening of capital markets, removing barriers to executive labor mobility, and improved access to information for foreign investors. More information from the Canadian government can be found here: `http://www.international.gc.ca/trade-agreements-accords-commerciaux/agr-acc/eu-ue/negotiations-negoiations.aspx?lang=eng&view=d`. More information from the EU commission can be found here: `http://ec.europa.eu/enterprise/policies/international/cooperating-governments/canada/index_en.htm`.

percent. The total foreign production in Canada would increase by a factor of 4/3.

Table 7: Counterfactual changes of lower EU-Canada MP costs

| | Difference in inward MP-shares | | Rel. welfare |
|---|---|---|---|
| | Canada | United States | |
| Canada | -10.5 | 0.05 | 102.44 |
| EU countries | 23.1 | -0.46 | 100.07 - 100.19 |
| Switzerland | -0.2 | 0.005 | 99.90 |
| United States | -12.4 | 0.41 | 99.96 |

*Notes:* Counterfactual: Reduction in variable and fixed MP costs between EU and Canada by 20 percent.

Simultaneously, part of the EU countries' increased investment in Canada is crowding out their previous production in the US. EU countries' production share in the US would fall from 5.61 to 5.15 percent. In relative terms, this is a decline by 7 percent. Canadian firms would react to higher relative wages in Canada and increase their activities in the US. However, not to the same extent as EU firms decrease their activities. The overall share of foreign production in the US would fall by 6 percent.

Of all countries, Canada would experience the largest welfare gains. The welfare gains in EU countries are positive but moderate in size and larger for smaller countries. The US and Switzerland would experience small welfare losses. The US economy is large enough that even though the diversion of EU investment from the US to Canada is substantial, it would not be affected much in terms of aggregate welfare.

# 5 Conclusion

I develop a trade & FDI model that incorporates both fixed costs to set up foreign plants and the possibility of export platform sales from the foreign plants. Fixed costs are motivated by firms' concentration of production in only a few locations. The possibility of export platform sales reflects the empirical fact that on average 40 percent of the output of US multinationals' foreign plants is sold to other foreign countries. While the motivation to include both fixed costs and export platforms into the model is strong, together they greatly complicate the solution method to the firm's profit maximization problem: The decision where to serve which market from becomes interdependent across markets. Building a product-level theory of multinational production, the model delivers elegant and intuitive closed-form expressions for the sales at the plant and profits at the firm level, conditional on the firm's location choice. This leaves a much smaller discrete choice problem for the firm - the choice of its optimal locations.

The model can be used to analyze both micro and macro data. In the first application, I investigate the sources of home bias in production using data on German multinational firms. I find that larger variable production costs abroad and fixed costs to set up foreign plants are similarly important in generating a large share of firm-level output at home relative to the share of the domestic economy in the global economy. In the second application, I calibrate my model to data on bilateral trade and multinational production between 12 Western European and North American countries while solving for the general equilibrium. I find that while my model with trade and MP implies similar gains from trade as a pure trade model, it implies much larger gains from foreign firms' technology improvements. The multinational production framework in this paper could also be a useful tool for policy analysis: The calibrated model suggests that the currently negotiated Canada-EU free trade and investment agreement could divert around seven percent of the production of EU multinationals from the US to Canada.

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# Appendices

## Appendix A Propositions

**Proposition 2.** *Let $K$ denote the number of countries in which firm $t$ has a plant. Let $r : \mathbb{R}^K_{++} \times \{0,1\}^N \times \Psi \rightarrow \mathbb{R}^K_{++}$ be the stacked vector of revenues as defined in equation (24). $\Psi = [\psi_{min}, \psi_{max}]^K$ where $\psi_{min} > 0$ and $\psi_{min} < \psi_{max} < \infty$. Then for any triple $\{r_t, \omega, Z\}$, the vector $\psi$ that solves $r_t - r(\omega, Z, \psi) = 0$ is unique.*

*Proof.* The proof shows that the conditions for the univalence theorem of Gale and Nikaido (1965) are satisfied. Clearly $r(\omega, Z, \psi)$ is differentiable with respect to $\psi$ and $\Psi$ is a closed rectangular region. It is left to show that Jacobian matrix of $r$ is a P-Matrix.

I simplify the expression in equation (24) in the following way. I drop the constants and define $\alpha = \frac{\theta+1-\sigma}{\theta}$. Given the assumptions made in the text, $0 < \alpha < 1$. I denote $c_{lm} = (\omega_l \tau_{lm})^{-\theta}$. Further, I drop the firm index $t$. Then $r_{t,l}$ becomes

$$r_l(c, Z, \psi) = \sum_m \widetilde{y_m} \frac{c_{lm}\psi_l}{\left(\sum\limits_{k \in Z} c_{km}\psi_k\right)^{\alpha}}$$

Note that

$$\begin{aligned}
\frac{\partial r_l}{\partial \psi_l} &= \sum_m \widetilde{y_m} \frac{-\alpha c_{lm} c_{lm} \psi_l + c_{lm}\left(\sum\limits_{k \in Z} c_{km}\psi_k\right)}{\left(\sum\limits_{k \in Z} c_{km}\psi_k\right)^{\alpha+1}} \\
&= \sum_m \widetilde{y_m} \frac{(1-\alpha) c_{lm} c_{lm} \psi_l + c_{lm}\left(\sum\limits_{k \neq l, k \in Z} c_{km}\psi_k\right)}{\left(\sum\limits_{k \in Z} c_{km}\psi_k\right)^{\alpha+1}} \\
&> 0
\end{aligned}$$

and for $k \neq l$

$$\frac{\partial r_l}{\partial \psi_k} = \sum_m \widetilde{y_m} \frac{-\alpha c_{km} c_{lm} \psi_l}{\left(\sum\limits_{k \in Z} c_{km}\psi_k\right)^{\alpha+1}} < 0$$

It is easy to see that $|\frac{\partial r_l}{\partial \psi_l}| > \sum\limits_{k \neq l} |\frac{\partial r_l}{\partial \psi_k}| \; \forall l$, hence the Jacobian matrix of $r$ is a strictly diagonally dominant matrix. This along with the fact that $\frac{\partial r_l}{\partial \psi_l} > 0 \; \forall l$ implies that the Jacobian matrix of $r$ is a P-Matrix.

Then the univalence theorem of Gale and Nikaido (1965) implies, whenever $r(\omega, Z, a) = r(\omega, Z, b)$, where $a, b \in \Omega$, then $a = b$. ■

## Appendix B Data

### B.1 German multinationals data

All parent companies and majority owned affiliates are from the manufacturing sector. Table 8 provides descriptive statistics on the multinational firms' activities in the countries included in my dataset. Table 9 documents the average foreign production share by the number of production locations.

### B.2 Macro part

This appendix describes the construction of the trade and MP shares. All data comes from Ramondo, Rodriguez-Clare, and Tintelnot (in process). The trade data is for the manufacturing sector only, while the MP data

Table 8: Descriptive Statistics
German multinationals activities

| Country | Number | Mean output | Median output |
|---|---|---|---|
| AUT | 91 | 76.3 | 34 |
| BEL | 45 | 235.3 | 37 |
| CAN | 36 | 536.0 | 28.5 |
| CHE | 70 | 58.3 | 17 |
| DEU | 665 | 625.8 | 98 |
| ESP | 117 | 191.9 | 32 |
| FRA | 191 | 107.7 | 30 |
| GBR | 121 | 119.4 | 23 |
| IRL | 18 | 36.3 | 19.5 |
| ITA | 100 | 65.0 | 27.5 |
| NLD | 46 | 83.1 | 25 |
| USA | 211 | 569.0 | 26 |

Notes: Output in million Euro.

Table 9: Foreign production shares

| Cardinality production locations | Number | Mean | Std |
|---|---|---|---|
| 2 | 474 | 0.26 | 0.20 |
| 3 | 102 | 0.32 | 0.18 |
| 4 | 40 | 0.35 | 0.19 |
| 5 | 23 | 0.39 | 0.16 |
| 6 | 14 | 0.46 | 0.15 |
| $\geq 7$ | 12 | 0.48 | 0.06 |
| all | 665 | 0.29 | 0.20 |

Note: Statistics for 12 Western European and North American countries. If all manufacturing multinational firms and affiliates in all countries are included, the average foreign production share is .32.

covers the entire non-financial sector of the economy. I implicitly assume that the MP in the service sector is proportional to the MP in the trade sector. The same assumption is being made by Arkolakis, Ramondo, Rodriguez-Clare, and Yeaple (2012). All data are averages over the years 1996-2001.

#### B.2.1 Trade shares

$$Absorption_m = GrossProduction_m + TotalWolrdImports_m - TotaWorldlExports_m - TotOtherImports_m$$

where $TotOtherImports_m$ represents the total imports by country $m$ from countries not included in the analysis.

$$TradeShare_{lm} = \frac{X_{lm}}{Absorption_m}$$

### B.2.2 MP shares

Let $Y_{il}$ denote the value of output produced in country $l$ by firms originating from country $i$. The construction of the MP shares accounts for the set of countries is not meant to represent the entire global economy (though an important part of it, with good local coverage, e.g., Western Europe and North America)). Further, the total production of firms at home is not directly observed. I therefore take data on gross non-financial production in the respective country, and subtract the MP from 50 other source countries contained in Ramondo, Rodriguez-Clare, and Tintelnot (in process), which has the same sectoral coverage. This gives me an estimate of the value of local production, $Y_{ii}$.

$$MPShare_{jl} = \frac{Y_{jl}}{\sum\limits_{i \in C} Y_{il}}$$

where $C$ denotes the set of countries included in the analysis.

# Appendix C Calculation of individual level parameters

The estimation in section 3 delivers a distribution of fixed costs draws across the population of observed multinational firms. With these estimates I derive the distribution of fixed costs for each multinational firm conditional on its observed location choice, $Z_t$, and the location-specific productivity vector, $\psi_t$. We can then calculate the mean value of fixed costs that were actually paid to set up a plant in the respective countries. To my knowledge, Revelt and Train (2000) were first to use such a procedure to infer information about the tastes of each sampled customer from the estimates of the distribution of tastes in the population with a nonlinear - mixed logit - discrete choice model.

Let $\beta$ denote the parameter vector of estimates in section 3. The productivity vector across plants of firm $t$, $\psi_t$, can be calculated given $r_t$ and $\beta$. The density of the fixed cost draws across countries conditional on having chosen a plant in country $l$ can be written as

$$u(f \mid Z_t, \psi_t, \beta) = \frac{Pr(Z_t \mid \psi_t, f) z(f \mid \beta)}{\int_f Pr(Z_t \mid \psi_t, f) z(f \mid \beta) df},$$

where

$$Pr(Z_t \mid \psi_t, f) = \int_\phi Pr(Z_t \mid \phi, f) k(\phi \mid \psi) d\phi,$$

and

$$k(\phi \mid \psi_t) = \frac{g(\phi) \prod_{l: Z_{t,l}=1} h(\frac{\psi_{t,l}(\omega, \sigma_\epsilon)}{\phi} \mid \beta)}{\int_{\phi'} g(\phi') \prod_{l: Z_{t,l}=1} h(\frac{\psi_{t,l}(\omega, \sigma_\epsilon)}{\phi'} \mid \beta) d\phi'},$$

and

$$Pr(Z_t \mid \phi, f) = \mathbb{1}\{E_\epsilon(\Pi | \phi, Z_t, \epsilon, f; \beta) \geq E_\epsilon(\Pi | \phi, Z', \epsilon, f; \beta) \quad \forall Z'\}.$$

The mean of fixed costs for firm $t$ is

$$\bar{f}^t = \int f u(f \mid Z_{t,l}, \psi_t, \beta) df,$$

and the average fixed cost in country $l$ of firms who actually have a plant there is

$$= \frac{\sum_{t=1}^{T} \bar{f}_l^t Z_{t,l}}{\sum_{t=1}^{T} Z_{t,l}}.$$

Similarly, the density function of the unobserved productivity level $\phi$, given location choice $Z_t$ and location-specific productivity levels $\psi_t$ can be written as

$$v(\phi \mid Z_t, \psi_t, \beta) = \frac{Pr(Z_t \mid \phi) \prod_{l:Z_{t,l}=1} h(\frac{\psi_{t,l}(\omega,\sigma_\epsilon)}{\phi} \mid \beta) g(\phi)}{\int_{\phi'} Pr(Z_t \mid \phi') \prod_{l:Z_{t,l}=1} h(\frac{\psi_{t,l}(\omega,\sigma_\epsilon)}{\phi'} \mid \beta) g(\phi') d\phi'},$$

where

$$Pr(Z_t \mid \phi) = \int_f Pr(Z_t \mid \phi, f) df.$$

As above for fixed costs, we can then calculate the mean core productivity level for firm $t$ and the mean productivity level for those firms who set up an affiliate in a particular country.