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Structural Estimates of Factor Substitution from Firm-Level Panel Data on Multinational Corporations

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Abstract

We develop an empirical approach that provides a general framework for studying the structure of production of multinational corporations (MNCs). The approach treats the MNCs' factors of production in different countries as separate inputs into a single general production technology that incorporates an unobservable firm-specific productivity shock. We estimate the parameters of the production technology using a new firm-level panel dataset and use them to construct the first ever estimates of how easily MNCs can substitute capital, labor, and materials within and between countries. The estimates provide a structural basis for (1) assessing the numerous proposed explanations of the nearly perfect correlation of domestic aggregate fixed investment and national saving; (2) determining whether outsourcing could have contributed significantly to the growing US wage gap between high-skilled and low-skilled workers; and (3) evaluating different tax policy proposals.

JEL Classification: C14, D24, E23, F21
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1 Introduction

> After producing 20 million sticks of chewing gum a day at the same California plant for more than 40 years, one might assume that Wm. Wrigley Jr. Co. was stuck on Santa Cruz. Wrong.
>
> Last week the Chicago-based gum Goliath announced it would shut its Santa Cruz plant, eliminating 311 local jobs over the next year. It will make up the slack at its two other US factories. Wrigley separately announced that on Monday it will break ground on a new $25 million factory in St. Petersburg (Russia, not Florida).
>
> The company says the economics of producing in Santa Cruz no longer made cents. With slower growth in the West and faster production and wrapping machinery, the local plant has been operating at less than 60 percent capacity.
>
> San Francisco Chronicle, 30 April 1996.

Multinational corporations (MNCs), such as Wrigley, are continually evaluating where to allocate factors of production, like capital, labor, and materials, to service domestic and international markets. MNCs' consider a variety of factors — such as after-tax input prices, demand, and technological progress — in making these decisions. National governments face the problem of how to best design public policy under these circumstances — whether it be pro-active or otherwise.

One of the most important public policy tools governments wield is tax policy. The optimal tax policy should minimize efficiency loss which, in the case of MNCs, depends on the degree to which they can substitute among inputs located in different countries. If domestic and foreign inputs can be substituted relatively easily, then taxes on MNCs in one jurisdiction can lead the firm to relocate production. This protects the relatively mobile factor inputs from taxation but shifts the incidence to the relatively immobile factors, resulting in substantial efficiency costs. In the theoretical literature on open economy optimal taxation the standard assumptions are that fixed capital is internationally mobile, labor is immobile, and countries are price takers in the world market for capital. Under these assumptions, optimal tax theory suggests that there should be no capital income taxation at all because MNCs will move abroad in response to even the smallest tax increase. However, all developed countries impose capital income taxes. An explanation for this observation may simply be that the theoretical assumptions are wrong. Instead, the institutional structure of open economy capital income taxation is consistent with internationally immobile capital and labor (see, e.g., Gordon 1986, 1992 and Razin and Sadka 1991).

The key issue for formulating corporate tax policy, then, is how easy it is to substitute among inputs in different countries. The empirical literature on fixed capital mobility begins with Feldstein and Horioka (1980), who first documented that there is a nearly perfect correlation between changes in domestic aggregate fixed investment and national saving. In other words, countries with low savings rates apparently do not make up for the low savings by acquiring capital from abroad. One explanation is that domestic investment is essentially constrained by domestic savings; that is, investors do not borrow from abroad. Many subsequent studies have demonstrated the robustness of this finding by replicating, extending, and refining it, although some studies advance other explanations for the correlation (see, e.g., Feldstein 1983, 1995; Dooley, Frankel, and Mathieson 1987; Tesar 1991; Stevens and Lipsey 1992; Ghosh 1995). The weight of empirical evidence continues to suggest that capital investment decisions depend on domestic fundamentals. This seems to contradict the empirical evidence that international interest rates are closely linked (see, e.g., Obstfeld 1986; Frankel 1993). However, despite years of research, the literature has not neared a consensus on an explanation of this seeming contradiction (see, e.g., the survey in Obstfeld 1993).[1]

The empirical literature on labor mobility focuses on it as one of the potential causes for the yawning wage gap between high-skilled and low-skilled workers. While a number of alternative explanations have been advanced to explain the wage gap, the labor mobility explanation posits that MNCs shift their low-skill labor-intensive operations — that is they "outsource" — from the US to take advantage of lower foreign wages. Several empirical studies suggest that international trade helps to explain the wage gap (see, e.g., Borjas and Ramey 1993; Katz and Murphy 1992). However, direct research on outsourcing finds that it contributes very little to rising wage inequality (see, e.g., Lawrence and Slaughter 1993; Slaughter 1995).

[1] The most recent theoretical research has focused on asymmetric information and income shifting (see, respectively, Gordon and Bovenberg 1994; Gordon and Mackie-Mason 1995) as possible factors explaining capital immobility, in contrast to more traditional arguments such as: capital controls and regulatory restrictions impede capital flow; and a positive domestic saving-investment correlation does not in itself provide evidence against capital mobility.

While the institutional structure of capital income taxation and the existing empirical literature support the view that fixed capital and labor are largely immobile among countries, Wrigley is just one example of a large and growing number of MNCs that have succeeded in locating factor inputs in different places and moving them among many different countries. The popular press and policymakers in the United States and other industrialized countries frequently argue that MNCs move fixed capital and jobs abroad (Ross Perot's "giant sucking sound") in order to take advantage of lower prices and less stringent regulation.

How can the view that capital, labor, and materials are immobile be justified given this casual empiricism? The basic theoretical model in international trade is of limited assistance since it defines a firm as plant that produces one good in one location (Markusen 1995). Multiplant firms are either excluded from the analysis or production decisions among the plants are assumed to be independent. In this setup, MNCs can only gain access to a foreign market by producing in it. Since production depends only on the anticipated output demand in the host country, domestic and foreign investment decisions are separable. As a result, when national governments formulate capital income tax policy, they have little incentive to take account of the characteristics and policies of other countries. Alternatively, if MNCs gradually overcome trade barriers (arising from trade restrictions or asymmetric information), they may gain significant production and tax benefits by substituting foreign for domestic factor inputs — regardless of whether the firm is horizontally or vertically integrated. If so, factor mobility could significantly erode any country's ability to impose capital income taxes. As a result, when national governments formulate activist capital income taxation policy, they would have to specially tailor it to differences in countries' characteristics and taxation policies.

Evaluation of these opposing viewpoints depends on estimates of the substitutability between MNCs' domestic and foreign inputs, which, in turn, depend on the structural parameters of the firm's production technology. Existing empirical research is of limited guidance for two reasons. First, most studies focus on reduced-form correlations of aggregate variables which, by definition, fail to identify the underlying structure of

MNCs' technology. Second, studies that explicitly estimate the parameters of the MNCs' technology use aggregate data and only focus on labor elasticities (Slaughter 1995).

In this paper, we develop a model of the MNC that allows us to directly estimate its production structure, including the degree of substitutability between factor inputs, the returns to scale, and total factor productivity (for the latter application see, Cummins 1998). The key feature of the model is its generality. The firm's stochastic dynamic decision problem treats factors in different countries as separate inputs into a single production technology that is rich enough to represent the behavior of both horizontally and vertically integrated MNCs. In addition, we assume that productivity is an input in the firm's production technology. Productivity is different from the other factor inputs for two reasons: first, it is a non-exclusive good within the firm, and hence a joint input in all production processes; and second, it is unobservable to the econometrician. Since we cannot observe the evolution of productivity we assume that it follows an exogenous Markov process. Firms, however, do observe their productivity since it is a state variable in their decision problem, and they choose their factor inputs accordingly.

Unobservable (to the econometrician) serially correlated state variables complicate estimation in two ways (Marschak and Andrews 1944; Griliches 1957). First, more variable inputs, such as labor and materials, are more closely correlated with the current realization of the productivity shock; and second, input demands are endogenous because they are determined in part by the firm's expectations about the realizations of shocks when those inputs will be used. As a consequence, inputs in place will be correlated with the current realization of the shock, and this will generate a simultaneous equations bias. Hence, standard econometric techniques provide biased estimates of the input demand and production parameters. In order to obtain unbiased parameter estimates, we build on the semiparametric procedure developed by Olley and Pakes (1996). The idea behind their approach is to use the model to express the unobservable state variable as some unknown function of the observable variables and use nonparametric techniques to approximate the unknown function. This is an increasing common approach to structural estimation (see, e.g., Guerre, Perrigne, and Vuong 1995; Li, Perrigne, and Vuong 1996; Wolak 1994). Unfortunately, this approach is not without drawbacks either. For example, under imperfect competition, when real output is constructed with common deflators across firms, the parameters of the production technology are biased downward in most circumstances (Klette and Griliches 1996). Hence for robustness, we also consider generalized method of moments (GMM) estimates that are unbiased and consistent in certain circumstances.

We estimate the model using a new firm-level panel dataset that contains data on output, capital, labor, and materials, for about 200 US MNCs for the period 1980 through 1995. We use our estimates of the technological parameters to calculate the firm-level substitutability of domestic and foreign factor inputs. These estimates provide a structural basis for (1) assessing the numerous proposed explanations of the nearly perfect correlation of domestic aggregate fixed investment and national saving; (2) determining whether outsourcing could have contributed significantly to the growing US wage gap between high-skilled and low-skilled workers; (3) evaluating different tax policy proposals. Our findings suggest that (1) domestic and foreign fixed capital are relatively easy substitutes at the firm level; (2) outsourcing may be an important component of the increase in the US wage gap not because foreign labor displaces domestic labor, but because foreign capital does; and (3) capital income taxes on MNCs are largely shifted and result in substantial efficiency costs.

The paper is organized as follows. Section 2 introduces the theoretical model. Section 3 characterizes the features of the model formally. Section 4 presents our econometric procedure. Section 5 describes the dataset. Section 6 discusses the estimation results. The final section concludes. We collect proofs, details of the model and estimator, and a description of how the variables are constructed in three appendices.

2 Theoretical Model

We develop a model of the structure of production of MNCs that has three primary features. First, the MNC uses multiple factor inputs indexed by the country in which it operates. Second, the production technology explicitly incorporates unobservable firm-specific productivity shocks. Finally, the model combines these two features in a dynamic decision problem with a single general production technology that allows variable elasticities of substitution between inputs.

The MNC uses a vector of quasi-fixed factors of production consisting of the parent and affiliates' period t capital, $\mathbf{K}_{it} = \{K_{ijt}\}_{j=1}^{n}$, where j indexes firm i's n locations of capital. The variable factors of production are labor, $\mathbf{L}_{it} = \{L_{ijt}\}_{j=1}^{n}$ and materials, M_{it}.[2] The firm produces gross output of a homogenous product, Y, using a quasi-concave production function:[3]

$$Y_{it} = F(\mathbf{K}_{it}, \mathbf{L}_{it}, M_{it}, l, t, \epsilon_{it} | \boldsymbol{\alpha}), \tag{1}$$

where l indexes the countries in which the MNC has affiliates. This index is introduced as an argument to account for productivity differences across locations.[4] Similarly, t is introduced as an argument to account for disembodied technical change. The variable ϵ is a stochastic disturbance that we discuss in detail below. The parameter vector $\boldsymbol{\alpha}$ describes the technical coefficients of production. The goal of the econometric procedure is to estimate this parameter vector.

According to our formulation inputs that are spatially separate are included in a single production technology. This technology, however, is empirically cumbersome since MNCs vary in the number of countries in which they operate (i.e., n is not the same for each i). Additional structure is imposed by assuming that affiliates' factor inputs are weakly separable from the parent's inputs. This means that the affiliates'

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[2] It is likely that capital and labor are heterogeneous within each location, as well as across locations, but this has to be ignored because our data do not distinguish different types of capital and labor. Cummins and Dey (1997) use firm-level panel data to estimate a model with heterogeneous capital goods, although they cannot distinguish the location of capital.

[3] For generality, it would be desirable to relax the assumption that output is homogeneous and incorporate differentiated products. Unfortunately, there are no data on the types of products each firm produces and where they produce them. The homogeneity assumption is innocuous when the firm produces differentiated products whose elasticities of substitution are unity because, in this case, the heterogeneous outputs can be aggregated into a single homogeneous one without loss of generality. It is also notable that while the production technology restricts the final output to be homogeneous, intermediate outputs that are inputs into the final output can be heterogeneous. For example, consider a firm like Boeing that manufactures the wings for its planes in Japan and marries them to the airframes in the US. The assumption of homogeneity disallows heterogeneous type of airplanes (unless they are unit elastic substitutes) but allows heterogeneous outputs in the sub-production processes, in this case, wings and airframes.

[4] This formulation means that otherwise identical MNCs can produce different quantities of output depending on the country in which their affiliates are located. For example, an MNC with an affiliate in Germany may be more productive than an otherwise identical one with an affiliate in France because German infrastructure is — at least for the sake of the example — superior.

inputs are perfect substitutes for the parent's inputs. While this restricts the elasticities of substitution between the parent and affiliates' inputs to be the same, it does not restrict the sign or magnitude of the elasticity; nor does it restrict the elasticities of substitution between the affiliates' factors. The assumption allows the parent firm's inputs to be separated from the aggregates of the affiliates' inputs:

$$Y_{it} = F(K_{idt}, K_{ift}, L_{idt}, L_{ift}, M_{it}, l, t, \epsilon_{it} | \alpha), \tag{2}$$

where d and f index the domestic parent and aggregate foreign affiliate, respectively.[5] For MNCs with affiliates in multiple countries the interpretation of the index l in equation (2) is different than in equation (1). In equation (2) these MNCs all receive the same shock, regardless of the countries in which they have affiliates.[6] This simplification ensures that there is only a single locational productivity shock for each firm.

Labor and materials are assumed to be costlessly adjustable and the costs of domestic and foreign capital are p_d and p_f. For MNCs with affiliates in multiple countries the foreign costs of capital are aggregated into a single foreign cost of capital p_f using country-level capital stocks as weights.

The structural disturbance to the firm's production process, ϵ_{it}, is log-additively separable from the other arguments in equation (2) and consists of two components. The first component is a non-negative, mean-one, multiplicative stochastic disturbance, ω_{it}, that represents an index of the firm's productivity. The firm (but not the econometrician) observes ω_{it} and optimizes with respect to it. The shock, ω_{it}, has a known

[5] The technical difficulty with estimating a production technology that includes MNCs with affiliates in different numbers of countries is that MNCs' implicitly report zeros for inputs in the countries in which they do not operate. The Box-Jenkins generalization of the translog introduced by Caves, Christensen, and Swanson (1981) does allow zeros for inputs, but this approach introduces many additional parameters that would greatly complicate both our estimation procedure and the interpretation of the results. In section 6, we gauge whether our empirical results are affected by the simplifying assumption by comparing them to the results from a subsample of the data that contains only MNCs with a single affiliate.

[6] This formulation means that MNCs with affiliates in many countries can produce different quantities of output than ones that have affiliates in only a single country. However, the particular countries in which the affiliates are located does not affect the productivity. For example, an MNC with affiliates in France and Germany has the same productivity as an otherwise identical MNC with affiliates in the UK and Canada. However, the productivity of these two MNCs can be different than an otherwise identical MNC with a single affiliate, regardless of the country in which it is located.

distribution that is serially-correlated over time and independently and identically distributed (iid) across firms.[7] The second component is a non-negative, mean-one, multiplicative stochastic disturbance, ε_{it}, that represents a shock to productivity realized after input decisions are made. This shock is assumed to be iid over time and across firms. Alternatively, one could think of ε_{it} as measurement error.

We assume that the production technology can be approximated by a translog function. We assume the translog because it is a flexible functional form that provides a second-order approximation to any arbitrary continuous twice-differentiable production function. Hence, it allows for variable elasticities of substitution between inputs. It is important to recognize that we are not assuming that the translog is the actual production technology, only that it approximates the technology. Finally, we assume that profitability differences across firms result from Hicks-neutral technical change (HNTC). Thus all factor demands are affected equiproportionally by technical change.[8]

Given the assumptions of HNTC and log-additive separability of the structural disturbance to production, the translog function we use to approximate the general production technology is expressed as:

$$
\begin{aligned}
y_{it} = \; & \alpha_0 + \alpha_{L_d} l_{idt} + \alpha_{L_f} l_{ift} + \alpha_{K_d} k_{idt} + \alpha_{K_f} k_{ift} + \alpha_M m_{it} \\
& + \frac{1}{2}\left[\alpha_{L_dL_d} l_{idt}^2 + \alpha_{L_fL_f} l_{ift}^2 + \alpha_{K_dK_d} k_{idt}^2 + \alpha_{K_fK_f} k_{ift}^2 + \alpha_{MM} m_{it}^2\right] \\
& + \alpha_{L_dL_f} l_{idt} l_{ift} + \alpha_{L_dK_d} l_{idt} k_{idt} + \alpha_{L_dK_f} l_{idt} k_{ift} + \alpha_{L_dM} l_{idt} m_{it} \\
& + \alpha_{L_fK_d} l_{ift} k_{idt} + \alpha_{L_fK_f} l_{ift} k_{ift} + \alpha_{L_fM} l_{ift} m_{it} \\
& + \alpha_{K_dK_f} k_{idt} k_{ift} + \alpha_{K_dM} k_{idt} m_{it} + \alpha_{K_fM} k_{ift} m_{it} \\
& + \sum_{k=1}^{K-1} \alpha_k D_k + \sum_{l=1}^{L-1} \alpha_l D_l + \sum_{t=1}^{T-1} \alpha_t D_t + \omega_{it} + \varepsilon_{it},
\end{aligned}
\tag{3}
$$

[7]This setup is general enough so that an alternative formulation could allow each firm to have a distinct ω_{it} indexed by country, provided that the different productivity indexes enter the production technology log-additively.

[8]It would be desirable to examine whether the results are robust to different types of augmenting technical change: Harrod (only labor augmenting), Solow (only capital augmenting), and Leontief (only value-added augmenting). But this extension is left to future research because it is unclear how we can identify the technological parameters using our econometric technique when technical change is biased.

where lowercase letters represent the logarithms of variables (including ω and ε); D_t are year dummy variables that represent disembodied technical change over time; D_l are location dummy variables that capture differences in productivity across locations; and T and L are the total numbers of years and locations in the panel, respectively.

3 Formal Analysis of MNC's Production Technology

Since we study MNCs' production, total output is a composite function of all of the multinational's inputs, domestic *and* foreign. This means that inputs that are geographically separated are included in a single production technology. Productivity is assumed to be a freely mobile, joint input into the spatially separated production operations. This composite formulation nests the standard view of the firm in the international trade literature that treats domestic and foreign production processes independently. Recall that this approach represents factor inputs that are geographically separated by altogether separate production functions (with or without productivity as an argument in each). In our general framework, the hypothesis that spatially separated processes are independent is a testable restriction on the general technology. In other words, the composite production technology in equation (2) could represent a function that is the sum of two spatially independent production processes like the following:

$$\begin{aligned} Y &= F(K_d, K_f, L_d, L_f, M) \\ &= f_1(K_d, L_d) + f_2(K_f, L_f) + M \\ Y - M &= VA = f_1(K_d, L_d) + f_2(K_f, L_f), \end{aligned} \tag{4}$$

where VA is value-added.[9] Thus, the framework does not impose or preclude any level of input substitutability. If the standard view is rejected, then the alternative is a more general characterization of the MNCs technology.

[9]In our empirical approach we use the Translog which is composed of the sum of the logarithims of the inputs. Taking logarithims of equation (4) yields the logarithim of the sum of the inputs, not the sum of the logarithims. Hence the reader might might be concerned that the Translog cannot approximate the technology described by equation (4). However, this confuses the fact that the Translog is used to approximate the technolgy, not as the actual technology. Since the Translog is a flexible functional form it can approximate *any* twice continuously differentiable function. The intution for why flexible functional forms can approximate so many different types of functions is that they are Taylor approximations; in the case of the Translog, a taylor approximation that builds off of the Cobb-Douglas production function.

The composite production technology could represent a vertically integrated MNC that uses production in different locations as inputs in the assembly of a final product. In this case, substitution between inputs reflects the transfer of intermediate production tasks among countries as factor prices change. Consider again the example of Boeing from footnote 3. If the cost of capital in Japan increases, Boeing might shift the production of wing sections to another foreign country or back to the US. Alternatively, the composite production technology could represent a horizontally integrated MNC with self-contained plants in different countries. In this case, substitution between inputs reflects changes in production in a given country in response to changes in local demand, exchange rates, factor prices, or transactions and transportation costs. Consider again the example of Wrigley. If factor prices in Russia are sufficiently low Wrigley might shift gum production to Russia from the US.

We can make the foregoing discussion of the MNC's production technology rigorous by characterizing it formally and formulating testable features of it. We show the equivalence of certain elasticities of substitution and certain features of the technology. The idea is to use the elasticities of substitution, which are estimable, as a way to characterize the underlying technology of the MNC, which is unobservable. The practical implication of our propositions is that they facilitate hypothesis tests — applied in section 6 — where the elasticity condition is equivalent to testing hypotheses about the parameters of the production technology.

We are especially interested in the restrictions on the production technology that are consistent with the view of the MNC represented in equation (4). In order to derive these, however, several intermediate steps are necessary. We first present a general proposition that can be used to characterize the technologies and then derive increasingly more restrictive versions of the technologies, the most restrictive of which is the independent process technology: (1) a two-level CES production technology (i.e., the lower level is composed of strongly separable subfunctions and the upper level is a CES superfunction of all the subfunctions); (2) a Cobb-Douglas nesting of the subfunctions (i.e., the production technology is Cobb-Douglas in all the subfunctions); and, (3) independent Cobb-Douglas technologies for domestic and foreign production, and materials (i.e., the production technology is composed of three strongly separable Cobb-Douglas technologies). The first two of these cases are appealing because they characterize more general technologies than the independent process view but are still simple.

We introduce some notation before the propositions. The firm produces gross output Y with production function $F(X)$, where $X = \{x_1, x_2, \dots, x_n\}$,

$$Y = F^*(X) = F(x_1, x_2, \dots, x_n).$$

Let the set of n inputs, $N = \{1, 2, \dots, n\}$, be partitioned into S subsets $\{N_1, N_2, \dots, N_S\}$ and $\{x\}$ into S bundles $\{x^{(1)}, x^{(2)}, \dots, x^{(S)}\}$ so that $x_i \in x^{(s)}$ if $i \in N_s$. Homothetic weak separability with respect to the partition is necessary and sufficient for the production function to be represented:

$$Y = F[f_1(x^{(1)}), f_2(x^{(2)}), \dots, f_S(x^{(S)})], \tag{5}$$

where $f_s(x^{(s)})$ is a positive strictly quasi-concave homothetic production subfunction of only the elements in N_s. For example, the domestic and foreign inputs could be grouped into separate subprocesses, $Y = F(f_1(K_d, L_d), f_2(K_f, L_f), M)$. Let θ_s (θ_r) denote the cost share of the subfunction f_s (f_r).

Proposition 1 *The technology described by equation (5) has Allen elasticities of substitution between factor i and j (AES_{ij}) given by the following:*[10]

$$\begin{aligned} AES_{ij} &= \sigma_N(s,s) + \frac{\sigma^s_{ij}}{\theta_s}, \quad && i, j \in N_s, \\ AES_{ij} &= \sigma_N(r,s), && i \in N_r,\ j \in N_s, \quad r \neq s, \end{aligned} \tag{6}$$

where σ^s_{ij} is the intraprocess partial elasticity of substitution, $\sigma_N(s,s)$ is the own elasticity of substitution for processes s, and $\sigma_N(r,s)$ is the interprocess elasticity of substitution between processes r and s.

Proof: See appendix A.

[10]The Allen elasticity is the constant-output cross-price elasticity of demand between inputs i and j divided by the share of the jth input in total cost. See subsection 6.2 for a discussion of properties of the Allen elasticity and preferable alternatives for characterizing substitutability. We cast the discussion in this subsection in terms of the Allen elasticity concept because it simplifies the exposition and the proofs.

According to proposition 1 the elasticity of substitution between (1) a pair of factors in the same subprocess is composed of intra- and inter-process elasticities and (2) a pair of factors belonging to different subprocesses is equal to the elasticity of substitution between subprocesses.

In the following propositions we consider three special cases of the production technology in equation (5). The first case is when it is strongly separable and takes the form of the two-level CES:

$$Y = F(z) = \left[\sum_{s=1}^{S} \alpha_s z_s^{-\rho}\right]^{-1/\rho}, \quad \alpha_s > 0, \quad -1 \leq \rho = \frac{1-\sigma_N}{\sigma_N} < \infty, \tag{7}$$

where

$$z_s = f_s(x^{(s)}) = \left[\sum_{i \in N_s} \beta_i^{(s)} (x_i^{(s)})^{-\rho_s}\right]^{-1/\rho_s}, \quad \beta_i^{(s)} > 0, -1 \leq \rho_s = \frac{1-\sigma_{ij}^s}{\sigma_{ij}^s} < \infty.$$

When production takes this form we have the following proposition.

Proposition 2 *The Allen elasticities of the two-level CES are:*

$$\begin{aligned} AES_{ij} &= \sigma_N + \frac{1}{\theta_s}\left(\sigma_{ij}^s - \sigma_N\right) \quad && i, j \in N_s, \\ AES_{ij} &= \sigma_N, && i \in N_r, \quad j \in N_s, \quad r \neq s. \end{aligned} \tag{8}$$

Proof: See appendix A.

The second special case is when equation (7) is a Cobb-Douglas nesting (i.e. Cobb-Douglas in {z}). In this case $\rho \to 0$ and then equation (7) is written:

$$Y = F(z) = A \prod_{s=1}^{S} (z_s)^{\alpha_s}, \alpha_s > 0. \tag{9}$$

When production takes this form we have the following proposition.

Proposition 3 *The Allen elasticities of the strongly separable Cobb-Douglas nesting are:*

$$\begin{aligned} AES_{ij} &= 1 + \frac{1}{\theta_s}\left(\sigma_{ij}^s - 1\right) \quad && i, j \in N_s, \\ AES_{ij} &= 1, && i \in N_r, \quad j \in N_s, \quad r \neq s. \end{aligned} \tag{10}$$

Proof: See appendix A.

The final special case is when equation (7) is strongly separable and takes the form of a linear technology of Cobb-Douglas subfunctions (i.e. linear in $\{z\}$). In this case $\rho = -1$ and then equation (7) is written:

$$Y = F(z) = \sum_{s=1}^{S} \alpha_s z_s, \quad \alpha_s > 0. \tag{11}$$

When production takes this form we have the following proposition.

Proposition 4 *The Allen elasticities of the strongly separable Cobb-Douglas nesting are:*

$$\begin{aligned} AES_{ij} &= \sigma_{ij}^{s} \qquad i, j \in N_s, \\ AES_{ij} &= \infty \qquad i \in N_r, \quad j \in N_s, \quad r \neq s. \end{aligned} \tag{12}$$

Proof: See appendix A.

This final proposition is especially interesting because it represents the fully flexible independent production view of MNCs. Specifically, this proposition establishes when total domestic output is solely the output of the domestic production subfunction and total foreign output is solely the output of the foreign production subfunction. In which case we can express value-added as the sum of the two subfunctions representing domestic and foreign production, as in equation (4):

$$\begin{aligned} Y &= F[f_1(x^{(1)}), f_2(x^{(2)}), \ldots, f_S(x^{(S)})] \\ &= f_1(K_d, L_d) + f_2(K_f, L_f) + f_3(M) \\ Y - M &= VA = f_1(K_d, L_d) + f_2(K_f, L_f), \end{aligned} \tag{13}$$

where we have assumed that $f_3(M) = M$.

We contrast this characterization with the island plants view in which geographically separate operations are unaffected by factor price changes abroad because output is not substitutable across countries. This is because certain types of goods are non-tradable or effectively non-tradable because of trade barriers or differences in tastes. For example, suppose that the French prefer to consume baguettes over Wonder bread regardless of the relative price. Then the demand for baguettes in France is unaffected by price changes in Wonder bread. Under this view the elasticities of substitution between geographically separate inputs would appear to be zero.

4 Econometric Estimation

In this section we describe the basic setup of our econometric procedure and relegate the details of the estimator to appendix B. The standard econometric approach for estimating technological parameters is to estimate the system of factor share equations derived from the cost function dual to the production function. The rationale for estimating the cost function is that prices are more likely to be exogenous than quantities in disaggregated data. However, this approach is unsuitable for firm-level data since the input prices paid by firms are usually poorly measured or unobserved.[11] An alternative that exploits the rich firm-level variation in input quantities is to estimate the production function itself (recently, Mundlak 1996 has advocated a return to estimating the primal technology). But as discussed in the introduction these estimates are biased because the MNC's productivity, ω, is a serially correlated unobservable. The procedure we use corrects for the bias so we can take advantage of the rich firm-level variation in quantities in our dataset.

There are two problems in consistently estimating the parameters of equation (3). First, current input choices are a function of the unobserved (from the perspective of the econometrician) serially-correlated state variable ω. Any econometric procedure that fails to account for the endogeneity will bias upward estimates of the coefficients. The bias will be most severe for the variable inputs because they are more highly correlated with current realizations of ω. Second, selection bias results from firms exiting the sample. As discussed in detail in section 5 firms can exit either because they cease to operate or because they stop reporting country-level data for their affiliates. Either way, exit truncates the observed distribution of ω as a function of the production inputs. If firms with larger capital stocks expect larger future profits for any given ω — so they would continue in operation for lower realizations of ω — selection bias will cause the

[11]Griliches (1979) argues that even if such data were widely available they would contain insufficient variation for estimation.

conditional expectation of ω to be decreasing in K. Any econometric procedure that fails to account for this will bias downward estimates of the capital coefficients.

We adapt the three step procedure Olley and Pakes (1996) introduced to address the two problems discussed above. The derivation extends theirs to consider our more general production technology. The procedure provides consistent estimates of the coefficients of equation (3) by expressing the unobservable state variable, ω, in terms of observable variables. In particular, we show in appendix B that ω can be expressed as some unknown function of observables:

$$\omega_{it} = g_t(K_{ijt}, I_{ijt}, p_{ijt}). \tag{14}$$

where I is investment; and j indexes domestic and foreign variables.

The equation we estimate in the first step is derived by substituting equation (14) into equation (3):

$$\begin{aligned} y_{it} = {} & \alpha_0 + \alpha_{L_d} l_{idt} + \alpha_{L_f} l_{ift} + \alpha_M m_{it} + \frac{1}{2}\left[\alpha_{L_dL_d} l_{idt}^2 + \alpha_{L_fL_f} l_{ift}^2 + \alpha_{MM} m_{it}^2\right] \\ & + \alpha_{L_dL_f} l_{idt} l_{ift} + \alpha_{L_dK_d} l_{idt} k_{idt} + \alpha_{L_dK_f} l_{idt} k_{ift} + \alpha_{L_dM} l_{idt} m_{it} \\ & + \alpha_{L_fK_d} l_{ift} k_{idt} + \alpha_{L_fK_f} l_{ift} k_{ift} + \alpha_{L_fM} l_{ift} m_{it} + \alpha_{K_dM} k_{idt} m_{it} + \alpha_{K_fM} k_{ift} m_{it} \\ & + \sum_{t=1}^{T-1} \alpha_t D_t + \sum_{l=1}^{L-1} \alpha_l D_l + h_t(K_{ijt}, I_{ijt}, p_{ijt}) + \varepsilon_{it}, \end{aligned} \tag{15}$$

where

$$\begin{aligned} h_t = {} & \alpha_{K_d} k_{idt} + \alpha_{K_f} k_{ift} + \frac{1}{2}\left[\alpha_{K_dK_d} k_{idt}^2 + \alpha_{K_fK_f} k_{ift}^2\right] + \alpha_{K_dK_f} k_{idt} k_{ift} \\ & + g_t(K_{ijt}, I_{ijt}, p_{ijt}). \end{aligned} \tag{16}$$

We estimate equation (15) semiparametrically by projecting y_{it} on the functions of domestic and foreign variable inputs (labor and materials), year and country indicator variables as regressors for D_t and D_l, and a fourth-order polynomial series in $(K_{ijt}, I_{ijt}, p_{ijt})$ as regressors for h_t. This is a standard semiparametric approach that has been shown to provide consistent estimates of the coefficients on the functions of the variable inputs (for details see, Pakes and Olley 1995; Robinson 1988; Newey 1995). The idea is that the coefficient estimates on the functions of the variable inputs are biased because they are correlated with the unobservable productivity shock. Consistent estimates are obtained when the shock is estimated as well. In our model this requires fitting a non-parametric approximation to h_t in terms of observables.

Since the distribution of the unobserved state variable ω is truncated by exit, the second and third steps implement a semiparametric version of a sample selection model. The second step estimates the selection mechanism. In appendix B, we show that the probability of survival, P_t, can be expressed as a function of observables as well. We estimate this probability using a fourth-order polynomial series in $(K_{ijt}, I_{ijt}, p_{ijt})$ as regressors.

In the final step, we use a semiparametric estimator that uses a fourth-order polynomial series in (P_t, g_t) as regressors to nonparametrically approximate the selection probability and the productivity shock. Conditional on these variables, the estimator provides consistent estimates on the remaining technological parameters on capital. In the results, we refer to the three step procedure generically as the "semiparametric" estimator.

5 Data

We estimate the model using a new firm-level panel dataset constructed from several sources. A detailed description of how the variables are constructed is contained in appendix C. In this section, important data issues for estimation are outlined and some features of the sample are presented.

The data on the US parent firms are from the Compustat industrial and full-coverage files. The data on affiliates are from the Compustat geographic segment file (for a detailed description see Cummins and Hubbard 1995). The geographic segment file, however, reports only a limited set of information on the foreign operations of MNCs. The data are recorded for seven years at a time. We combine three seven-year panels to obtain a dataset extending from 1980 to 1995.[12] The tax parameters are updated and

[12]Due to differences in accounting reporting requirements prior to 1980, the panel begins in 1980.

expanded from Cummins, Hassett, and Hubbard (1995). There are about 200 parent and affiliates with complete data for at least one year.

There is no requirement by either the Financial Accounting Standards Board (FASB) or the Securities and Exchange Commission that MNCs must disclose country-level data in the geographic segment data. As a result, the degree of specificity between company reports varies. For example, consider two companies operating in the same countries. Company A might report three different geographic areas: France, Germany, and Canada. Company B might report two different geographic areas: France and "other foreign."

The accounting literature stresses that considerable caution should be exercised in making inferences about data reported for regions and for groups of countries (see, e.g., Pointer and Doupnik 1993; Senteney and Bazaz 1992). No conclusions about their relative importance can be made from the data. Consider Company B again. Since it aggregates Canada and Germany into "other foreign" there is no way of separating its foreign operations into specific countries. Fortunately, about 15 percent of the firms in the sample separately report activities in the US and in at least one other country.[13] We limit the sample to these firms.

About one-quarter of the firms that report country-level data report for more than one country. When this is the case, it makes the specification of the production technology problematic. To enable comparison among MNCs, we assume that the affiliates inputs are weakly separable from the parent's inputs so that we can aggregate across affiliates to obtain a single foreign affiliate. When we aggregate in this way we denote the affiliates' country as "multiple." The individual countries for which Compustat reports affiliate data are Australia, Canada, France, Germany, Japan, and the United Kingdom. These six countries receive the majority of US MNCs' FDI.

Since firms may choose the level of aggregation at which they report their geographic segment data, those that report by country are perhaps materially different from those that report more coarsely. In other words, the country-specific sample is not necessarily a random sample of the whole sample in the presence of non-reporting or "reporting

[13]The Compustat geographic segment file reports data for only the total of within country operations. Thus the data for MNCs with multiple affiliates within the same country are aggregated over the affiliates.

exit," as contrasted with true economic exit. Studies in the accounting literature have found some evidence in support of reporting selection — even though the focus of the accounting research is not explicitly on selection. Balakrishnan, Harris, and Sen (1990), for example, show that the geographical composition of firm's activities are statistically and economically significant predictors of future earnings and equity valuations. The overall evidence suggests that firms may face differential trade-offs between the benefit of revealing more information to the financial markets and the cost of revealing too much detail to competitors. This competitive disadvantage may be relatively more severe when firms that are required to report geographic segment data by the FASB compete against firms that need not, usually because they are foreign incorporated firms that do not file according to US GAAP.

It is likely then that firms choose whether to report country-specific geographic segment data based on expectations about the financial and product market structure. While we do not have a model for this behavior the same approach used to control for the bias generated by true exit offers a way to control for this type of selection as well. In the model presented in appendix B, current profits are a function of the firm's own state variables and a vector of the state variables of the other firms in the market. The latter is a counting measure which lists the vector of state variables of all the firm's active competitors — which is referred to as the market structure (see Ericson and Pakes 1995). The market structure then consists of a list of tuples of state variables for all the active firms.

Just as selection bias results from the fact that exit truncates the observed distribution of ω as a function of the production inputs, bias also results from reporting choices that truncate the observed distribution of ω as function of production inputs and equilibrium market structure. Since the market structure is identical across firms in a given period, the selection probability presented in appendix B (equation (40)) for true exit is also applicable for reporting exit. It follows that the derivation in appendix B of equation (43) is applicable for reporting exit as well. Thus when we estimate the selection probability P_t and use it to correct for selection bias resulting from true exit, this procedure also corrects for bias resulting from reporting exit.

In the geographic segment file, affiliates' data are reported in nominal US dollars. There are a number of different methods to translate variables measured in different currencies into real figures that are comparable across time and across countries. We use a method suggested by Leamer (1988) that translates foreign currencies into US dollars in each year using the current exchange rate and then divides by the relevant US price deflator to form the real series. Since the parent's and affiliate's data are already reported in US dollars in the geographic segment file, we assume that firms accurately translate host country currencies into US dollars in each year using the current exchange rate — as they are required to do under FASB regulations. Then the real series are obtained by dividing the variables by the relevant US price deflator. Leamer (1988) concludes that this method performs well relative to others in constructing comparable investment and capital stock series. To the extent that there is mismeasurement due to exchange rate fluctuations it is unlikely that the qualitative empirical results would be affected because there are year effects in the regressions. However, the year effects would no longer be pure measures of disembodied technical change.

Tables 1 through 3 summarize our data on US MNCs. Table 1 reports the number of US foreign affiliates for which at least some data are available. Data are available over the time period from 1980 through 1994. While the number of affiliates reporting information varies from year to year (generally growing over the period), we were able to draw upon from 275 to 756 MNCs for our sample.

Table 2 presents aggregate US parent and affiliate sales, tangible fixed assets and employees. The sample aggregates account for a large fraction (greater than half for each variable) of the aggregates reported in the BEA's annual survey of US direct investment abroad (Survey of Current Business, various issues). Thus while the sample does not contain all the US parents and their affiliates, the sample nonetheless contains the largest US MNCs and by that measure is representative.

Table 3 reports summary statistics (biyearly) for parent's and affiliates' sample variables. The sample variables are output (Y), parent and affiliate capital (K_d and K_f, respectively) and parent and affiliate labor (L_d and L_f, respectively). Included are the mean, medians, quartiles and minimums and maximums of the variables used in the estimating equations. The number of MNCs declines significantly from table 1 for three reasons. First, firms reporting zeros for any of the variables were deleted as is necessitated by the translog specification. Second, the construction of the replacement value of the capital stock eliminated firms. Finally, before beginning our estimation procedure, we identified observations that we determined were outliers. We deleted observations when output, domestic capital, or foreign capital were less than $1 million in 1987 dollars. We also deleted observations when the number of domestic or foreign employees was less than 2. We chose cutoffs like this to delete very small MNCs and those that maintain only a marketing or "test trial" operation abroad. Our results are robust to other similar rules for deleting outliers. Our qualitative results are insensitive to outliers in other variables. The total number of observations for which there is complete data is 1800 which represents more than 200 different MNCs.

The first quartile of the sample variables shows that the sample contains a large number of relatively small MNCs. For example, there are several MNCs that have a total labor force of less than five employees.[14] The upper quartile shows that the sample contains many of the largest US MNCs (e.g., General Motors).

6 Empirical Results

6.1 Estimates of Technological Parameters

Table 4 presents the parameter estimates of the spatially separable and general production technology models using ordinary least squares and the semiparametric estimator. The first and second columns report the estimates for the spatially separable production technologies. The parameter estimates of these models appear severely misspecified in comparison to the other estimates. Estimates of the factor shares indicate decreasing returns to scale and unrealistically low estimates of the labor shares. Column three reports the baseline estimates of the general joint production model without correcting for endogeneity and selection bias.

Column four reports estimates of equation (15) using the semiparametric estimation procedure. The parameter estimate of α_{L_d} in equation (15) from the first step of

[14]The MNCs with small numbers of employees were overwhelmingly concentrated in the computer software and specialty instruments industries.

the semiparametric estimator is 0.413; the estimate of α_{L_f} is 0.350. Both parameter estimates are statistically significant. The parameter estimate of $\alpha_{L_f L_f}$ is -0.204, the largest in absolute magnitude of the squared terms on labor, and is statistically significant. The parameter estimates of α_{K_d} and α_{K_f} are, respectively, 0.174 and 0.095. Both estimates are statistically significant. The parameter estimate of $\alpha_{K_d K_f}$ is -0.071 and is statistically significant. However, substitution possibilities cannot be gauged by casual examination of the magnitude and signs parameter estimates.

6.2 Elasticities of Substitution

Applied production studies usually report Allen elasticities of substitution (AES_{ij}) between factors i and j or price elasticities of demand (PES_{ij}). When there are more than two inputs, however, these elasticities are potentially misleading measures of the ease of substitution between factors or the curvature of the production function. For this reason we report the Morishima elasticities (MES_{ij}) and the shadow elasticities of substitution (SES_{ij}) (see Blackorby and Russell 1981, 1989; McFadden 1963; Mundlak 1968).[15] We also report the Allen and price elasticities to maintain comparability to previous applied research. This type of comparison is particularly important because inputs can be AES compliments and MES substitutes. Thus drawing inferences from the AES about the ease of substitution between factors is potentially misleading.[16]

The elasticities of input substitution are calculated from the parameter estimates of the semiparametric translog in column four of table 4 at the full sample means and the 1994 means in table 3. Tables 5 through 8 present the AES, PES, MES, and SES for all the inputs. Summarizing all the tables, there are four main findings about cross-country substitutability. First, domestic and foreign labor are very weak compliments

[15] The Morishima elasticity of substitution is the log derivative of an input quantity ratio (taken from the compensated demands) in the ith coordinate direction. It provides a correct measure of the ease of substitution, and is — in a frictionless world — a sufficient statistic for assessing the effects of changes in price or quantity ratios on relative factor shares. The elasticities are related in the following way:

$$PES_{ij} = \frac{\partial \ln i}{\partial \ln p_j} \quad ; \quad MES_{ij} = PES_{ji} - PES_{ii}$$
$$AES_{ij} = PES_{ij}/S_j \quad ; \quad SES_{ij} = S_i MES_{ji} + S_j MES_{ij}$$

where i is the ith factor input; p_j is the jth factor price; and S_j is the cost share of factor j.

[16] Another reason why we calculate the Allen elasticities is that they are a convenient way to describe the nature of the production technology (see section 3). In this case the difference between the Allen and other elasticity concepts is irrelevant.

and the degree of complementarity has declined to nearly zero by 1994. Second, domestic labor and foreign capital are relatively strong substitutes (defined as greater than unit elastic substitutes). Third, likewise, domestic capital and foreign labor are relatively strong substitutes. Finally, domestic and foreign capital are also relatively strong substitutes.[17]

The *AES* and *PES* own elasticities of substitution are calculated as well.[18] Using the full sample means the own elasticities on domestic and foreign labor are quite small and are relatively large on domestic and foreign capital (consistent with the fact that the labor shares are large relative to the capital shares). Using the 1994 sample means, the qualitative results are the same, except foreign labor has an own elasticity that is comparable to those on domestic and foreign capital.

The within-country factor substitutability is also reported in tables 5 through 8. The *AES* and *PES* elasticities tell a different story from the *MES* and *SES* elasticities so we concentrate on the later two. Using either the full sample or 1994 sample means, the $MES_{K_dL_d}$ indicates substitutability (0.592 and 0.459, respectively), while the $MES_{L_dK_d}$ is about zero (-0.043 and -0.024, respectively). Recalling the definition of the *MES*, this means when the price of domestic capital increases there is substitution to domestic labor but when the price of domestic labor rises there is almost no effect on domestic capital. Using either the full sample or the 1994 sample means, the $MES_{K_fL_f}$ indicates complementarity (-1.161 and -1.291, respectively), while the $MES_{L_fK_f}$ is about zero (0.092 and -0.086, respectively). This means that when the price of foreign capital increases, both foreign capital and foreign labor decrease, but when the price of foreign labor increases, foreign capital is almost unaffected. Since the *SES* is the share-weighted average of the *MES*s, the $SES_{K_dL_d}$ indicates some substitutability and the $SES_{K_fL_f}$ indicates some complementarity.

[17] Shepard's lemma makes it simple to calculate standard errors on the elasticities when they are constructed from estimates of the system of factor share equations derived from the cost function dual to the production function. However, when the production function is estimated Shepard's lemma cannot be used. Instead, calculating the elasticities involves taking determinants of bordered Hessians. To our knowledge the distribution theory for these calculations is unknown and we suspect that this is why studies do not report standard errors on elasticities from production function estimates. In a future revision, we will do so using bootstrapping (i.e., distribution free) techniques.

[18] The own elasticities are undefined using the *MES* and *SES*.

The *AES*s' between domestic and foreign factors indicate that domestic and foreign labor are complements and that domestic and foreign capital are substitutes. If the island plants characterization of MNC's production were correct, both elasticities would have to be positive (and equal to infinity). While there are no standard errors on the elasticities and the null hypothesis of an elasticity equal to infinity is impossible, the estimated signs of the parameters would have to be different in order for both *AES*'s to be positive. Since the parameter estimates are statistically significant from zero (either positive or negative) we can reject the hypothesis that the island plants technology accurately characterizes the MNCs in our sample.

6.3 Discussion

There is an emerging literature on the ease of substitutability between domestic and foreign labor (see, Lawrence and Slaughter 1993; Slaughter 1995). Our findings that the two are weak complements are qualitatively similar to the results in those studies. Taken together, these results suggest that it is likely that cross-country labor substitution contributes little to rising wage inequality. But there is another channel through which input substitution can affect the wage gap suggested by our more general approach: US parents can substitute domestic labor for foreign capital. Our findings suggest that it is relatively easy to substitute domestic labor for foreign capital, and that it has been getting easier over time. Outsourcing may be an important component of the increase in the US wage gap not because foreign labor displaces domestic labor, but because foreign capital does.

The results for capital contrast sharply with those from reduced-form estimates of correlations of aggregate variables typical of the macro/international literature on capital mobility. Those studies find that capital is largely immobile with implied elasticities of substitution near zero. However, as emphasized by several authors, positive domestic saving-investment correlations that have been interpreted as evidence of capital immobility do not themselves provide evidence against mobility (for a review of these arguments see, e.g., Obstfeld 1993). Our large elasticities of substitution support this interpretation of the previous empirical studies.

In table 10 we use our estimates to study how tax changes affect the steady state factor demands of a representative MNC. We use the parameter estimates in column four of table 4 and the 1994 values of the average (across firms) factor prices, depreciations, tax parameters, and discount rate. The entries in the first four columns of the table are the percentage changes in the steady state values of variables resulting from the tax change. The entries in the last four columns are the percentage change in the steady state factor shares resulting from the tax change. The effect of home and host country corporate tax changes on US MNCs is complicated because the US uses the "source" principle of taxation (i.e., MNCs are taxed on their worldwide income). Hence, we consider only the effects of a reinstatement of the investment tax credit (ITC) in the home or host country.

When an ITC of 10 percent is reinstated in the US it results in about a 13 percent drop in the cost of capital. This drop leads to about the same size increase in the representative MNC's domestic capital stock and about a 9 percent increase in domestic employment. The US capital and labor shares increase commensurately, by about 4 and 1.5 percent, respectively. Even though the foreign affiliate's factor shares decline in response to the increase in the US ITC, the steady state foreign capital stock increases. This illustrates that it is important to separate the output and substitution effects of the cut in the cost of capital. The changes in the factor shares reflect substitution from foreign factors to domestic ones in response to the cut in the domestic cost of capital. However, foreign investment actually increases because steady state output increases enough to counteract the substitution effect. When an ITC of 10 percent is introduced in the host country it leads to more modest increases in own country steady state capital and labor, about 5 percent and 8 percent, respectively. In this case the parent's capital and labor are both greater, in spite of the decline in their factor shares. This is especially interesting: despite the ease of substitution between foreign capital and domestic factors, US investment and employment increase in response to host country tax incentives because the output effect of these incentives dominates the substitution effect.

These simulations suggest that MNCs can easily shift their behavior in response to changes in the fundamentals that affect the net return to investment in factors of production. As a result, countries may face increasing pressure on corporate tax revenues, as companies shift production to the lowest tax countries. This raises the possibility that tax policy, in particular, can cause substantial efficiency losses. Thus when national governments formulate activist tax policy, it may be efficacious to specially tailor it to differences in countries' characteristics and taxation policies so as to minimize the efficiency cost of taxation.

7 Conclusion

We develop an empirical approach that provides a general framework studying the structure of MNCs' production and use it to examine how easy it is to substitute factors of production between different countries. Our findings suggest that (1) domestic and foreign fixed capital are relatively easy substitutes at the firm level; (2) capital income taxes on MNCs are largely shifted and result in substantial efficiency costs; (3) outsourcing may be an important component of the increase in the US wage gap not because foreign labor displaces domestic labor, but because foreign capital does.

A Proofs of Propositions

The following proofs are helpful for thinking about the structure of the MNC's production technology. The proof of proposition 1 is based on results in Blackorby, Primont, and Russell (1978) and Denny and Fuss (1977), and follows Anderson and Moroney (1992). The proofs of propositions 2 through 4 follow directly from proposition 1. In particular, the results in propositions 2 and 3 were first shown by Sato (1967) and Uzawa (1962), respectively. We include these for the convenience of the reader, and do not intend to imply that the propositions are original theoretical work on our part.

A.1 Proof of Proposition 1

Define the unit cost function for process $c_s(z, p^{(s)})$:

$$c_s(z, p^{(s)}) = \min_{x^{(s)}}\{p^{(s)} \cdot x^{(s)} : f_s(p^{(s)}) \geqq 1; \quad x,\, p \in \mathbb{R}_+^n\}, \tag{17}$$

where z is the output vector of the subprocesses; x and p are the input and price vectors, respectively. Define the unit cost function for total output $C(y, c_s)$:

$$C(y, c_s) = \min_{z}\{c \cdot z : F(z) \geqq 1; \quad z \in \mathbb{R}_+^s\}, \tag{18}$$

By Shephard's Lemma the factor demands are:

$$x_i(y, p) = y \frac{\partial C}{\partial c_s} \frac{\partial c_s}{\partial p_i} \quad i \in N_s. \tag{19}$$

This says that producing a unit of the final output requires $\partial C/\partial c_s$ of the sth subprocess which requires $\partial c_s/\partial p_i$, per unit, of the ith input; thus the product of these is the required amount of factor i needed to produce a unit of the final good.

The effects of a factor price change can be decomposed into three effects by log-differentiating equation (19):

$$\mathrm{d}\log x_i = \mathrm{d}\log y + \mathrm{d}\log\left(\frac{\partial C}{\partial c_s}\right) + \mathrm{d}\log\left(\frac{\partial c_s}{\partial p_i}\right). \tag{20}$$

The first term on the right hand side is the output adjustment effect along the demand curve which can be rewritten as:

$$\begin{aligned} \mathrm{d}\log y &= -\eta \log P \\ &= -\eta \sum_{i=1}^{n} S_i \,\mathrm{d}\log p_i, \end{aligned} \tag{21}$$

where $-\eta$ is the price elasticity of demand; P is the output price; and S_i is the cost share of factor i.

The second term is the interprocess substitution effect which can be rewritten as:

$$\mathrm{d}\log\left(\frac{\partial C}{\partial c_s}\right) = \theta_s \sigma_N(s,s) \sum_{i\in N_s} \theta_i^{(s)} \mathrm{d}\log p_i + \sum_{r\neq s} \theta_r \sigma_N(r,s) \sum_{i\in N_r} \theta_i^{(r)} \mathrm{d}\log p_i, \tag{22}$$

where θ_s (θ_r) is the cost share of the output of the subprocess z_s (z_r); $\theta_i^{(s)}$ ($\theta_i^{(r)}$) is the cost share of factor i in subprocess s (r); $\sigma_N(s,s)$ is the intraprocess elasticity of substitution within process s; $\sigma_N(r,s)$ is the interprocess elasticity of substitution between processes r and s. In terms of the cost function, the intra- and interprocess elasticities of substitution are, respectively:

$$\sigma_N(s,s) = \frac{C(y,c_s)C_{ss}(y,c_s)}{C_s(y,c_s)C_s(y,c_s)}, \tag{23}$$

$$\sigma_N(r,s) = \frac{C(y,c_s)C_{rs}(y,c_s)}{C_r(y,c_s)C_s(y,c_r)}. \tag{24}$$

The third term is the intraprocess substitution effect along the subprocess isoquant which can be rewritten as:

$$\mathrm{d}\log\left(\frac{\partial c_s}{\partial p_i}\right) = \sum_{i\in N_s} \theta_i^{(s)} \sigma_{ij}^{s} \,\mathrm{d}\log p_i, \tag{25}$$

where σ_{ij}^{s} is the elasticity of substitution between factors i and j in subprocess s. In terms of the cost function, the intraprocess elasticity of substitution is:

$$\sigma_{ij}^{s} = \frac{c_s(z,p^{(s)})c_{s_{p_i p_j}}(z,p^{(s)})}{c_{s_{p_i}}(z,p^{(s)})c_{s_{p_j}}(z,p^{(s)})}. \tag{26}$$

Note that this term is zero when the factor whose price has changed is in another subprocess.

Using equations (21), (22), and (25), and the identity $S_j = \theta_j^{(s)}\theta_s$, we can derive the cross-price elasticity of demand (PES_{ij}) as the change in demand for factor i resulting from a change in the jth factor price:

$$\begin{aligned} PES_{ij} &= \frac{\partial \log x_i}{\partial \log p_j} = S_j\left[\sigma_N(s,s) + \frac{\sigma_{ij}^s}{\theta_s} - \eta\right] \quad i,j \in N_s, \\ PES_{ij} &= \frac{\partial \log x_i}{\partial \log p_j} = S_j\left[\sigma_N(r,s) - \eta\right] \qquad i \in N_r, j \in N_s, r \neq s. \end{aligned} \tag{27}$$

The proof is completed by noting that the definition of the Allen elasticity of substitution is: $AES_{ij} = PES_{ij}/S_j$, holding output constant.

A.2 Proof of Proposition 2

Consider a CES nesting of the S subprocesses with parameter ρ that defines the interprocess elasticity of substitution $\sigma_N = 1/(1+\rho)$. In this case Sato (1967) shows that $\theta_s\sigma_N(s,s) = \sigma_N(\theta_s - 1)$ and $\sigma_N(r,s) = \sigma_N$. These results can be substituted into equation (27) to prove the second proposition:

$$\begin{aligned} AES_{ij} &= \sigma_N + \frac{1}{\theta_s}\left(\sigma_{ij}^s - \sigma_N\right) \quad i,j \in N_s, \\ AES_{ij} &= \sigma_N, \qquad i \in N_r, \quad j \in N_s, \quad r \neq s. \end{aligned} \tag{28}$$

A.3 Proof of Proposition 3

Consider the further simplification of a Cobb-Douglas nesting of the S subprocesses. Then $\rho \to 0$ and $\sigma_N = 1$ and equation (28) reduces to the following:

$$\begin{aligned} AES_{ij} &= 1 + \frac{1}{\theta_s}\left(\sigma_{ij}^s - 1\right) \quad i,j \in N_s, \\ AES_{ij} &= 1, \qquad i \in N_r, \quad j \in N_s, \quad r \neq s. \end{aligned} \tag{29}$$

A.4 Proof of Proposition 4

Consider the case when $\rho = -1$ and $\sigma_N = \infty$. This is the case of linear technology and, using the result the $\theta_s = 1$ when there is linear technology, equation (28) reduces to the following

$$
\begin{aligned}
AES_{ij} &= \sigma^s_{ij}, \quad i, j \in N_s, \\
AES_{ij} &= \infty, \quad i \in N_r, \quad j \in N_s, \quad r \neq s.
\end{aligned}
\tag{30}
$$

B Model and Estimation Details

The MNC begins each period t by deciding whether to exit or continue operations for another period.[19] In addition to true economic exit, the dataset contains missing data because firms can choose how they disclose their geographic segment data.[20] Whether to report data or not is a type of exit rule so in presenting the model we refer generically to the exit rule regardless of whether exit is caused by true exit or by non-reporting.

If the firm exits it receives some liquidation value Ψ. If not, the firm chooses variable inputs and realizes profits, conditional on the beginning-of-period values of the state variables, capital $\mathbf{K}$, the cost of capital $\mathbf{p}$, and firm efficiency ω. Let the profit function be $\pi_t(\mathbf{K}_t, \mathbf{p}_t, \omega_t)$ ($\pi_{\mathbf{K}} > 0$, $\pi_{\mathbf{KK}} < 0$). Following Ericson and Pakes (1995) the profit function also depends on market structure — as do the value and investment demand functions presented below. Since the market structure is assumed identical across firms in a given period but not between periods, it is omitted from the notation and the profit, value, and investment demand functions are instead indexed by time.[21]

The cost of capital is observable to both the firm and the econometrician. Productivity ω evolves according to an exogenous Markov process. The distribution of ω_{t+1} is given by the family of functions

$$
F_\omega = \{F(\cdot|\omega_t), \omega \in \Omega\}, \forall t. \tag{31}
$$

[19]The firm index i is suppressed to economize on notation except where essential.

[20]This is described in detail in section 5 where we discuss the data.

[21]Notice that this assumption makes these functions empirically intractable because the functional forms are allowed to be different each period. This issue is irrelevant for our econometric procedure though because we do not estimate these functions. Instead we use them to estimate the production technology which is assumed to be the same in all periods.

At the end of the period, the firm chooses a vector of investment **I** and the capital stock **K** depreciates at a fixed geometric rate δ, so the capital stock next period is

$$K_{j,t+1} = (1-\delta)K_{jt} + I_{jt}. \tag{32}$$

The firm is assumed to be risk-neutral and to maximize the expected present discounted value of future net profits. The Bellman equation for the firm is thus

$$\begin{aligned} V_t(\mathbf{K}_t, \mathbf{p}_t, \omega_t) = \max\Big\{ \Upsilon, \sup_{\mathbf{I}_t}\Big\{ \pi_t(\mathbf{K}_t, \mathbf{p}_t, \omega_t) - C(\mathbf{I}_t, \mathbf{K}_t) \\ +\beta_t \mathrm{E}[V_{t+1}(\mathbf{K}_{t+1}, \mathbf{p}_{t+1}, \omega_{t+1}) | \Theta_t]\Big\}\Big\}, \end{aligned} \tag{33}$$

where E is the expectations operator; β_t is the time t discount factor; $C(I_t, K_t)$ is the real cost of adjusting the capital stock ($C_{\mathbf{I}} > 0$, $C_{\mathbf{II}} > 0$, $C_{\mathbf{K}} < 0$, $C_{\mathbf{KK}} < 0$). and Θ_t is the time t information set. In equation (33) the firm compares its liquidation value to the expected discounted revenue for continuing operations for another period. If the values of the state variables make continuing operations profitable compared to liquidation, the firm chooses an optimal level of gross investment.

The general solution to this value function is very complicated to evaluate. But, following the work of Olley and Pakes (1996), the exit rule and investment demand function generated by the solution can be used to obtain econometric estimates of the structural parameters of the firm's production technology. Define the indicator function ι_t for exit as

$$\iota_t = \begin{cases} 1 & \text{if } \omega_t \geq \underline{\omega}_t(\mathbf{K}_t, \mathbf{p}_t) \\ 0 & \text{otherwise,} \end{cases} \tag{34}$$

where $\underline{\omega}$ is the critical value determining exit. Notice that since $V(\mathbf{K}_t, \mathbf{p}_t, \omega_t)$ is increasing in **K**, $\underline{\omega}_t(\mathbf{K}_t, \mathbf{p}_t)$ is decreasing in **K**. Define the investment demand function as

$$\mathbf{I}_t = \mathbf{I}_t(\mathbf{K}_t, \mathbf{p}_t, \omega_t). \tag{35}$$

We assume that investment is an increasing function of of productivity, $\mathbf{I}_\omega(\mathbf{K}_t, \mathbf{p}_t, \omega_t) > 0$. The critical value in the exit rule $\underline{\omega}_t$ and the investment demand function $\mathbf{I}_t$ are functions of time because they are determined as part of the equilibrium market structure.

Provided that $\mathbf{I}_t > 0$ the investment demand function, equation (35), is invertable for the observables $(\mathbf{I}_t, \mathbf{K}_t, \mathbf{p}_t)$ and can be expressed as equation (14), which forms the basis for the first step of our econometric procedure:

$$\omega_t = g_t(\mathbf{I}_t, \mathbf{l}_t, \mathbf{p}_t).$$

Selection bias results from the fact that exit truncates the observed distribution of ω as a function of the production inputs. This generates an omitted variable:

$$E[\omega_t | \mathbf{k}_t, \mathbf{l}_t, \omega_{t-1}, \iota_t = 1] \tag{36}$$

in the conditional expectation

$$E[y_t | \mathbf{k}_t, \mathbf{l}_t, \omega_{t-1}, \iota_t = 1]. \tag{37}$$

Any econometric procedure that fails to account for this omitted variable will yield biased estimates of the capital coefficients.

The second step of our of econometric procedure estimates the selection mechanism for the model where the probability of survival is:

$$P[\iota_{t+1} = 1 | \underline{\omega}_{t+1}(\mathbf{K}_{t+1}, \mathbf{p}_{t+1}), \Theta_t] = P[\omega_{t+1} \geq \underline{\omega}_{t+1}(\mathbf{K}_{t+1}, \mathbf{p}_{t+1}) | \underline{\omega}_{t+1}(\mathbf{K}_{t+1}, \mathbf{p}_{t+1}), \omega_t]. \tag{38}$$

To show how to estimate this probability first define the distribution of ω_{t+1} conditional on the cost of capital vector, $\mathbf{p}$:

$$X_s = \{X(\cdot | \omega, \mathbf{p}), \omega \in \Omega, \mathbf{p} \in \Phi\}.$$

Then using the definition of F in equation (31) we can rewrite the survival probability as:

$$P[\omega_{t+1} \geq \underline{\omega}_{t+1}(\mathrm{K}_{t+1}, \mathrm{p}_{t+1}) | \underline{\omega}_{t+1}(\mathrm{K}_{t+1}, \mathrm{p}_{t+1}), \omega_t] = \mathrm{F}_t[\underline{\omega}_{t+1}(\mathrm{K}_{t+1}, \mathrm{p}_{t+1}), \omega_t]. \quad (39)$$

This probability can be expressed as a function of observables using the definition of X, the capital stock accounting identity, equation (32), and the inverted investment demand function, equation (14):

$$\begin{aligned} \mathrm{F}_t[\underline{\omega}_{t+1}(\mathrm{K}_{t+1}, \mathrm{p}_{t+1}), \omega_t] &= \mathrm{X}_t(\mathrm{I}_t, \mathrm{K}_t, \mathrm{p}_t) \\ &\equiv P_t, \end{aligned} \quad (40)$$

where P is the selection probability or, using the language of Rosenbaum and Rubin (1983), the propensity score. We estimate this probability using a fourth-order polynomial series in $(\mathrm{I}_t, \mathrm{K}_t, \mathrm{p}_t)$ as regressors.

For the final step, consider the expectation of y_{t+1}, given the estimates in the first step and conditional on survival:

$$\begin{aligned} &\mathrm{E}[y_{t+1} - \hat{\alpha}_{L_d} l_{d,t+1} - \hat{\alpha}_{L_f} l_{f,t+1t} - \hat{\alpha}_M m_{t+1} - \tfrac{1}{2}\left[\hat{\alpha}_{L_dL_d} l_{d,t+1}^2 + \hat{\alpha}_{L_fL_f} l_{f,t+1}^2 + \hat{\alpha}_{MM} m_{t+1}^2\right] \\ &-\hat{\alpha}_{L_dL_f} l_{d,t+1} l_{f,t+1} - \hat{\alpha}_{L_dK_d} l_{d,t+1} k_{d,t+1} - \hat{\alpha}_{L_dK_f} l_{d,t+1} k_{f,t+1} - \hat{\alpha}_{L_dM} l_{d,t+1} m_{t+1} \\ &-\hat{\alpha}_{L_fK_d} l_{f,t+1} k_{d,t+1} - \hat{\alpha}_{L_fK_f} l_{f,t+1} k_{f,t+1} - \hat{\alpha}_{L_fM} l_{f,t+1} m_{t+1} \\ &-\hat{\alpha}_{K_dM} k_{d,t+1} m_{t+1} - \hat{\alpha}_{K_fM} k_{f,t+1} m_{t+1} | \mathrm{k}_{t+1}, \iota_{t+1} = 1] \\ &= \alpha_0 + \alpha_{K_d} k_{d,t+1} + \alpha_{K_f} k_{f,t+1} + \tfrac{1}{2}\left[\alpha_{K_dK_d} k_{d,t+1}^2 + \alpha_{K_fK_f} k_{f,t+1}^2\right] + \alpha_{K_dK_f} k_{d,t+1} k_{f,t+1} \\ &\quad +\epsilon_{t+1} + \mathrm{E}[\omega_{t+1} | \omega_t, \iota_{t+1} = 1]. \end{aligned} \quad (41)$$

The last term in equation (41) can be manipulated to express the selection bias in terms of two unobservable indexes $\underline{\omega}_{t+1}$ and ω_t:

$$\begin{aligned} \mathrm{E}[\omega_{t+1} | \omega_t, \iota_{t+1} = 1] &= \int_{\underline{\omega}_{t+1}} \omega_{t+1} \frac{\mathrm{F}(d\omega_{t+1} | \omega_t)}{\int_{\underline{\omega}_{t+1}} \mathrm{F}(d\omega_{t+1} | \omega_t)} \\ &= k(\underline{\omega}_{t+1}, \omega_t). \end{aligned}$$

In order to control for the bias, the unobservables must be re-expressed in terms of observables. The selection equation in equation (40) can be inverted to express $\underline{\omega}_{t+1}$ as a function of P_t and ω_t. For fixed parameter values, h_t in equation (16) can be rearranged to express ω_t as a function of observables:

$$\omega_t = h_t - \alpha_{K_d} k_{dt} - \alpha_{K_f} k_{ft} - \frac{1}{2}\left(\alpha_{K_d K_d} k_{dt}^2 + \alpha_{K_f K_f} k_{ft}^2\right) - \alpha_{K_d K_f} k_{dt} k_{ft}. \tag{42}$$

Using these two results:

$$\begin{aligned} &k(\underline{\omega}_{t+1}, \omega_t) = \\ &k\Big\{\mathrm{F}^{-1}\Big[P_t, h_t - \alpha_{K_d} k_{dt} - \alpha_{K_f} k_{ft} - \frac{1}{2}\left(\alpha_{K_d K_d} k_{dt}^2 + \alpha_{K_f K_f} k_{ft}^2\right) - \alpha_{K_d K_f} k_{dt} k_{ft}\Big], \\ &h_t - \alpha_{K_d} k_{dt} - \alpha_{K_f} k_{ft} - \frac{1}{2}\left(\alpha_{K_d K_d} k_{dt}^2 + \alpha_{K_f K_f} k_{ft}^2\right) - \alpha_{K_d K_f} k_{dt} k_{ft}\Big\} \\ &\equiv k(P_t, g_t). \end{aligned} \tag{43}$$

The equation estimated in the final step is derived by substituting equation (43) into (41). Nonlinear least squares is used to estimate the resulting equation (which we do not reproduce to conserve space). This is also a semiparametric estimator that uses a fourth-order polynomial series in (P_t, g_t) as regressors to nonparametrically approximate $k(P_t, g_t)$ in equation (43). In the results presented, we refer to the results from the three step procedure generically as the "semiparametric" estimator.

C Dataset Construction

The variables used for econometric estimation are constructed as follows. Gross output is the sum of three items: the sum of net sales in the geographic segments; the parent's domestic net sales; and, when reported, the change in finished goods inventory. Gross output is deflated using the two-digit industry chain-weighted implcit price deflators for gross output in *Gross Output by Detailed Industry (1977-96)* from the US Bureau of Economic Analysis (BEA).

The replacement value of the parent's and affiliate's capital stock (hereafter capital stock) is constructed from the net stock of tangible fixed assets using the perpetual inventory method with the initial observation set equal to the book value of the firm's first reported observation.[22] The depreciation rate of parent and affiliate capital is assumed identical and calculated using the depreciation rates in Hulten and Wykoff (1981). Net investment is the change in each capital stock. Gross investment is the sum of net investment and depreciation. The capital stock and investment variables are deflated by the chain-weighted implicit price deflator for nonresidental fixed investment from the BEA.

We use total employees from Compustat and an auxiliary dataset to construct the parent's and affiliates' labor expense.[23] The BEA reports parent employment by industry and foreign affiliate employment by country and industry in an annual survey (for a detailed description of the data, see US Department of Commerce 1995). Using these data, we construct the percent of total employment accounted for by the parent and its affiliates by industry. We then match these industry weights to the firm-level data and construct parent and affiliate employees as the respective weight multiplied by total employees. The BEA's industry classification fails to exactly correspond to the firm-level industry codes. Typically, the BEA industry classification corresponds to a three-digit industry but in some cases it corresponds to a two- or four-digit one. Parent and affiliate employees are constructed using the most disaggregated BEA weight available. In most cases this is a good approximation of parent and affiliate employment since the survey from which the weights are constructed includes the MNCs in our firm-level data.[24]

Labor expense is calculated by multiplying total employees by the two-digit industry average hourly labor expense per employee. The average hourly labor expense is from the Bureau of Labor Statistics' (BLS) annual survey of employer cost for employee compensation which contains sector-level wage data (the sum of salary and benefits). The

[22] Major capital stock changes are deleted to eliminate clear discontinuities in the identity of the firm or measurement error.

[23] The direct measure of labor costs from Compustat is missing too frequently to be empirically useful.

[24] We confirmed the accuracy of this method by comparing our employee numbers to those from the companies' annual reports. We picked 10 MNCs at random from our sample and found that in all but two cases our method gave numbers within ten percent of those reported in their 1993 annual report.

publically available data are at the one-digit industry level. We obtained the two-digit data by special request. The BLS began the survey in 1986 so the values for earlier years are obtained be extrapolating backward using the sector-level employment cost index. We assume a 2000 hour work year to calculate the annual salary. Labor expense is deflated by the price index for total compensation.

Material expense is calculated by subtracting undeflated labor expense from total expense, defined as the sum of cost of goods sold, and, when reported, selling, general, and administrative expense. Materials are deflated using the two-digit industry chain-weighted implicit price deflators for intermediate inputs in *Gross Output by Detailed Industry (1977-96)* from the BEA. Value-added is gross output less materials.

Home and host country tax variables (federal and sub-federal corporate income tax rates, investment tax credits, depreciation allowances, and withholding tax rates on repatriated dividends) are updated and expanded from Cummins, Hassett, and Hubbard (1995).[25]

[25] Ken McKenzie kindly supplied some of the Canadian tax parameters.

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Table 1: Number of Foreign Affiliates in Dataset

Year	Australia	Canada	France	Germany	Japan	UK	Total
1980	15	215	4	12	4	38	275
1981	13	214	6	12	5	46	286
1982	16	230	6	11	7	52	315
1983	16	242	5	10	10	56	339
1984	18	258	7	14	16	67	374
1985	21	274	10	14	19	92	420
1986	25	284	11	17	24	119	458
1987	23	314	12	21	26	142	509
1988	27	358	12	21	28	182	570
1989	32	392	14	19	28	191	621
1990	38	408	18	32	36	198	675
1991	39	421	26	33	37	217	718
1992	37	425	32	38	43	228	754
1993	35	400	34	36	46	213	756
1994	31	339	29	35	40	168	664

Table 2: Selected Aggregate Data for Sample US Parents and Affiliates

	Sales		Tangible Fixed Assets		Employees	
Year	Parent	Affiliate	Parent	Affiliate	Parent	Affiliate
1980	488169.916	177118.090	232022.204	103185.668	4596494	206424
1981	493271.742	164172.021	231414.584	96835.188	4491420	200627
1982	428270.746	143762.655	220611.070	85992.655	3832755	161381
1983	442160.173	132025.256	242950.939	84602.634	3938132	167290
1984	508080.890	135456.517	290011.727	94171.903	4604607	187560
1985	551132.827	152510.548	359733.977	123293.581	4996321	232643
1986	539537.799	139090.866	337160.649	120908.018	4826889	235940
1987	554303.438	158227.986	369627.945	144189.805	4834209	229216
1988	599767.400	181200.882	553391.637	183062.712	4983200	263551
1989	636517.947	186106.698	638717.439	204417.147	5394083	225421
1990	630476.540	206988.791	635150.633	240476.929	5284975	249919
1991	609743.647	203981.398	637135.186	231592.782	5357815	219697
1992	434466.049	132111.375	345183.193	127366.465	3552111	166144
1993	373952.334	74247.844	350187.410	100983.595	2868053	131900
1994	343881.326	64267.192	332347.618	97233.968	2378522	113085

Variables are in millions of 1987 US dollars, except employees which is in units.

Table 3: Summary Statistics for Sample Variables (Biyearly)

Year	Number of MNCs	Variable	Mean	Min	Q1	Median	Q3	Max
1980	27	Y	1227.24	2.302	17.83	47.79	293.29	20000.70
		K_d	414.90	2.046	7.00	46.05	154.11	6804.35
		K_f	38.69	0.014	4.01	9.10	35.65	467.52
		L_d	10583.41	4.000	97.00	295.00	1646.00	212445.00
		L_f	2234.82	1.000	12.00	73.00	442.00	43555.00
1982	25	Y	1168.28	0.568	13.42	39.76	275.53	20186.48
		K_d	392.52	0.624	6.84	30.52	101.34	6311.32
		K_f	30.68	0.607	3.48	6.38	18.65	346.87
		L_d	10501.40	4.000	104.00	262.00	1710.00	199167.00
		L_f	2222.72	1.000	19.00	96.00	409.00	40833.00
1984	41	Y	1004.46	6.081	37.71	104.37	440.87	23357.38
		K_d	491.43	1.085	15.58	66.84	229.78	7568.34
		K_f	50.69	0.289	3.10	7.48	29.61	479.33
		L_d	9217.78	20.000	150.00	751.00	2472.00	244073.00
		L_f	1811.49	6.000	46.00	199.00	674.00	45927.00
1986	44	Y	535.68	6.668	29.65	142.13	468.07	8083.84
		K_d	263.56	0.605	23.80	92.63	193.51	1890.12
		K_f	42.18	0.502	3.64	9.32	24.88	436.83
		L_d	5152.32	12.000	169.50	1311.00	3449.50	65842.00
		L_f	1209.82	4.000	55.00	374.50	844.50	15658.00
1988	59	Y	795.47	0.371	20.43	101.29	647.86	13107.65
		K_d	337.63	0.029	15.19	54.19	280.57	2035.27
		K_f	60.35	0.098	3.13	13.74	39.27	561.70
		L_d	5980.10	7.000	134.00	894.00	3637.00	87130.00
		L_f	1410.59	3.000	41.00	225.00	1032.00	20069.00
1990	72	Y	742.08	0.510	22.90	87.40	524.46	13133.42
		K_d	324.50	0.366	11.52	38.05	240.03	2432.84
		K_f	67.46	0.039	2.22	8.32	42.26	641.33
		L_d	4990.15	6.000	121.00	462.50	2382.50	91668.00
		L_f	1256.61	2.000	41.00	192.50	891.50	22832.00
1992	74	Y	1144.17	0.689	45.31	209.73	860.90	12531.55
		K_d	480.95	0.476	34.88	121.14	690.58	2382.76
		K_f	87.33	0.030	3.64	13.98	108.35	872.54
		L_d	5672.97	9.000	214.00	894.50	3362.00	99885.00
		L_d	919.49	4.000	57.00	224.50	904.00	7910.00
1994	55	Y	847.48	0.799	29.32	134.30	523.34	12393.21
		K_d	509.18	3.556	22.57	101.88	493.45	5219.50
		K_f	75.71	0.004	4.60	10.11	69.38	714.73
		L_d	4284.49	21.000	135.00	801.00	2538.00	89357.00
		L_f	1149.87	15.000	41.00	194.00	758.00	20643.00
Full Sample	757	Y	863.30	0.006	24.68	110.83	474.11	23357.38
		K_d	392.00	0.029	16.52	65.83	289.08	7568.34
		K_f	62.66	0.004	3.30	10.29	38.57	872.54
		L_d	6047.14	2.000	150.00	772.00	2783.00	244073.00
		L_f	1405.18	1.000	40.00	223.00	788.00	45927.00

Variables are defined in the text. Variables are in millions of 1987 US dollars, except employees which is in units.

Table 4: Translog Production Function Parameter Estimates

Parameter	Ordinary Least Squares Domestic	Ordinary Least Squares Foreign	Ordinary Least Squares Joint	Semiparametric Unrestricted
α_{L_d}	0.556 (0.066)	—	0.185 (0.188)	0.413 (0.204)
α_{L_f}	—	0.160 (0.069)	0.342 (0.167)	0.350 (0.177)
α_{K_d}	0.356 (0.064)	—	0.308 (0.080)	0.174 (0.045)
α_{K_f}	—	0.424 (0.055)	0.073 (0.063)	0.095 (0.037)
$\alpha_{L_dL_d}$	-0.042 (0.022)	—	0.148 (0.091)	0.101 (0.103)
$\alpha_{L_fL_f}$	—	0.027 (0.016)	0.165 (0.064)	0.202 (0.083)
$\alpha_{K_dK_d}$	-0.030 (0.026)	—	0.040 (0.034)	0.021 (0.015)
$\alpha_{K_fK_f}$	—	-0.005 (0.016)	0.047 (0.018)	0.050 (0.018)
$\alpha_{L_dK_d}$	0.049 (0.022)	—	-0.043 (0.074)	0.009 (0.045)
$\alpha_{L_dK_f}$	—	—	0.074 (0.039)	0.107 (0.039)
$\alpha_{L_dL_f}$	—	—	-0.168 (0.031)	-0.204 (0.087)
$\alpha_{L_fK_d}$	—	—	0.061 (0.035)	0.070 (0.038)
$\alpha_{L_fK_f}$	—	0.032 (0.013)	-0.043 (0.028)	-0.061 (0.034)
$\alpha_{K_dK_f}$	—	—	-0.067 (0.024)	-0.114 (0.013)
Year Effects	Yes	Yes	Yes	Yes
Non-parametric Series:	No	No	No	Yes
First Stage				Polynomial in $(K_{ijt}, I_{ijt}, p_{ijt})$
Second Stage				Polynomial in $(K_{ijt}, I_{ijt}, p_{ijt})$
Third Stage				Polynomial in $(\hat{P}, \hat{g})$
Wald Statistic p-value	2.68 (0.102)	33.31 (0.000)	2.60 (0.107)	—
Number of Observations	1800	1800	1800	1151

The parameter estimates in columns one through three are based on the translog production function defined by equation (3) in the text. The parameter estimates in columns four and five are based on the semiparametric procedure described in the text. The dependent variable is domestic output for domestic production, foreign output for foreign production, and total output for joint production. Asymptotic standard errors are in parentheses. The Wald statistic is a test of constant returns to scale. The significance level of the test is in parentheses below the statistic.

Table 5: Allen Elasticities of Input Substitution (AES_{ij}) from the Semiparametric Unrestricted Translog Parameter Estimates

Full Sample Means				
Input	Domestic Labor (L_d)	Foreign Labor (L_f)	Domestic Capital (K_d)	Foreign Capital (K_f)
Domestic Labor (L_d)	-0.064	-1.409	-0.202	3.551
Foreign Labor (L_f)	-1.409	-0.012	2.590	-5.675
Domestic Capital (K_d)	-0.202	2.590	-1.638	1.882
Foreign Capital (K_f)	3.551	-5.675	1.882	-6.512

1994 Sample Means				
Input	Domestic Labor (L_d)	Foreign Labor (L_f)	Domestic Capital (K_d)	Foreign Capital (K_f)
Domestic Labor (L_d)	-0.432	0.024	-0.504	5.093
Foreign Labor (L_f)	0.024	-2.560	2.969	-7.906
Domestic Capital (K_d)	-0.504	2.969	-1.714	1.602
Foreign Capital (K_f)	5.093	-7.906	1.602	-6.585

Allen elasticities of input substitution are calculated from the parameter estimates of the semiparametric unrestricted translog in table 4 at the full sample means and the 1994 means in table 3.

Table 6: Price Elasticities of Input Demand (PES_{ij}) from the Semiparametric Unrestricted Translog Parameter Estimates

		Full Sample Means		
Input	Domestic Labor (L_d)	Foreign Labor (L_f)	Domestic Capital (K_d)	Foreign Capital (K_f)
Domestic Labor (L_d)	-0.020	-0.289	-0.083	0.392
Foreign Labor (L_f)	-0.439	-0.002	1.068	-0.627
Domestic Capital (K_d)	-0.063	0.531	-0.676	0.208
Foreign Capital (K_f)	1.106	-1.163	0.776	-0.719
		1994 Sample Means		
Input	Domestic Labor (L_d)	Foreign Labor (L_f)	Domestic Capital (K_d)	Foreign Capital (K_f)
Domestic Labor (L_d)	-0.147	0.006	-0.191	0.332
Foreign Labor (L_f)	0.008	-0.618	1.126	-0.516
Domestic Capital (K_d)	-0.171	0.717	-0.650	0.105
Foreign Capital (K_f)	1.732	-1.910	0.608	-0.430

Price elasticities of demand are calculated from the parameter estimates of the semiparametric unrestricted translog in table 4 at the full sample means and the 1994 means in table 3.

Table 7: Morishima Elasticities of Input Substitution (MES_{ij}) from the Semiparametric Unrestricted Translog Parameter Estimates

	Full Sample Means			
Input	Domestic Labor (L_d)	Foreign Labor (L_f)	Domestic Capital (K_d)	Foreign Capital (K_f)
Domestic Labor (L_d)	—	-0.419	-0.043	1.126
Foreign Labor (L_f)	-0.286	—	0.533	-1.161
Domestic Capital (K_d)	0.592	1.744	—	1.452
Foreign Capital (K_f)	1.111	0.092	0.927	—
	1994 Sample Means			
Input	Domestic Labor (L_d)	Foreign Labor (L_f)	Domestic Capital (K_d)	Foreign Capital (K_f)
Domestic Labor (L_d)	—	0.155	-0.024	1.879
Foreign Labor (L_f)	0.624	—	1.335	-1.291
Domestic Capital (K_d)	0.459	1.776	—	1.258
Foreign Capital (K_f)	0.762	-0.086	0.534	—

Morishima elasticities of input substitution are calculated from the parameter estimates of the semiparametric unrestricted translog in table 4 at the full sample means and the 1994 means in table 3.

Table 8: Shadow Elasticities of Input Substitution (SES_{ij}) from the Semiparametric Unrestricted Translog Parameter Estimates

	Full Sample Means			
Input	Domestic Labor (L_d)	Foreign Labor (L_f)	Domestic Capital (K_d)	Foreign Capital (K_f)
Domestic Labor (L_d)	—	-0.339	0.230	1.115
Foreign Labor (L_f)	-0.339	—	0.935	-0.346
Domestic Capital (K_d)	0.230	0.935	—	1.038
Foreign Capital (K_f)	1.115	-0.346	1.038	—

Shadow elasticities of input substitution are calculated from the parameter estimates of the semiparametric unrestricted translog in table 4 at the full sample means and the 1994 means in table 3.

Table 9: Shadow Elasticities of Input Substitution (SES_{ij}) from the Semiparametric Unrestricted Translog Parameter Estimates

	Full Sample Means				
Input	Domestic Labor (L_d)	Foreign Labor (L_f)	Domestic Capital (K_d)	Foreign Capital (K_f)	Materials (M)
Domestic Labor (L_d)	—	-0.312	1.776	3.087	4.163
Foreign Labor (L_f)	-0.312	—	2.421	0.694	1.033
Domestic Capital (K_d)	1.776	2.421	—	1.532	3.085
Foreign Capital (K_f)	3.087	0.694	1.532	—	1.346
Materials (M)	4.163	1.033	3.085	1.346	—

Shadow elasticities of input substitution are calculated from the parameter estimates of the semiparametric unrestricted translog in table 4 at the full sample means and the 1994 means in table 3.

Table 10: Steady State Effects of Tax Reform

Policy Change	Steady State Values K_d	K_f	L_d	L_f	Steady State Factor Shares K_d	K_f	L_d	L_f
Home Country ITC Increase	12.8	6.00	8.96	-1.34	4.17	-1.24	1.54	-8.06
Host Country ITC Increase	4.05	5.25	2.10	7.67	-0.01	1.07	-1.96	3.39

The simulations use the parameter estimates from the semiparametric unrestricted translog in table 4 and the 1994 values of the factor prices, tax parameters, and the discount rate. The entries are the percentage changes in the variables from their baseline values. The ITC increase is from zero to ten percent.