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OF GROWTH: ESTIMATES FROM
UNITED STATES MULTINATIONAL
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Taxation and the Sources of Growth: Estimates
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ABSTRACT

Capital income tax policy affects investment by the parent and affiliates of multinational corporations (MNCs). In a model in which technical advances are embodied in new capital, investment will translate directly into productivity gains. In this paper, I use this framework to guide the growth accounting decomposition and clarify the relationship between capital growth and overall firm growth. A semiparametric technique is used to correct for the usual bias that afflicts production function parameter estimates. These estimates are used to analyze the sources of MNC's growth. Three findings stand out: (1) growth in parent and affiliate capital are the most important sources of growth, with FDI contributing more to growth than the sum of the contributions of parent and affiliate employment, and materials; (2) productivity has boomed since 1992, due to productivity growth in MNCs with Canadian affiliates; (3) the investment elasticity of productivity growth is large and adjustment costs of investment are small, suggesting that changes in the after-tax price of capital result in robust investment which translates directly into productivity gains.

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1 Introduction

There are numerous careful studies of productivity at the firm level (for surveys, see Mairesse and Sassenou 1991; Griliches and Mairesse 1995). But none of these studies focus on United States multinational corporations (MNCs) despite their important role in the global economy.¹ In this study, I take a first step to fill this gap by estimating the parameters of the MNC's production technology and using them to study the sources of firm growth.

The growth accounting exercise is guided by a theoretical model that highlights how capital income tax policy can affect the dynamics of productivity. In the canonical Solow (1957) growth model tax policy can affect the growth rate of output by changing the growth rates of factor inputs such as capital and labor. But in this model tax changes cannot affect total factor productivity (TFP) directly since improvements in productivity are disembodied (i.e., technical change arrives as manna from heaven). However, when technical change is embodied in capital (see, e.g., Solow 1960; Domar 1963; Jorgenson 1966), tax policy can affect TFP through investment.² To gauge whether this role for tax policy is economically important, I construct a vintage capital model, based on Hulten (1992), with both embodied and disembodied technical change and use it to decompose the sources of growth of US MNCs.

The standard econometric approach for obtaining the technological parameters that can be used to study growth is to estimate the system of factor share equations derived from the cost function dual to the production function.³ These estimates can be used to calculate the measures of interest, such as factor shares, returns to scale, and TFP.

¹There are many studies that compare country-, industry-, and firm-level productivity among countries (see, e.g., Hulten 1990). However, these studies ignore MNCs, which operate in many different countries, by assuming that firms are based only in a single country.

²It is important to recognize that I am using TFP, not average labor productivity, as the measure of technical progress. Investment affects average labor productivity regardless of whether technical change is embodied or disembodied, while it affects TFP only when technical change is embodied.

³The traditional approach to productivity analysis is to use the index number methodology to calculate productivity indexes. The approach is simple because direct estimation of the underlying technology is unnecessary. However, for the index number approach to provide meaningful estimates of technical change, some strong assumptions must be maintained. It is necessary to assume constant returns to scale technology, competitive input and output markets, and instantaneous adjustment of all inputs to their desired demand levels. If any of these assumptions are violated, the productivity measure based on the index number approach will yield biased estimates of technical change. The econometric approach taken in this paper allows one to assess the validity of at least some of these assumptions by estimating the characteristics of the underlying technology (for a survey of the econometric approach to productivity analysis see Nadiri and Prucha 1997).

However, this approach is unsuitable for firm-level data since the input prices paid by firms are usually unobserved.⁴

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). There are two problems with this approach. First, more variable inputs, such as materials and labor, are more highly correlated with the current realization of any shock that is observable to the firm (e.g., a 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, I use a semiparametric procedure developed by Olley and Pakes (1996).⁵

Using this alternative approach I quantitatively examine the sources of output and productivity growth by decomposing the contributions of factor inputs (i.e., scale effects) and TFP. The results are quite surprising. Factor input growth, not TFP, is responsible for output growth in the MNCs in the sample. TFP actually declines over the sample period (1981–95), although this masks a steeper drop in the 1980s followed by a sharp recovery in the early 1990s. Among the inputs, growth in parent and affiliate capital are the most important. The importance of foreign direct investment (FDI) is especially striking. It contributes more to output growth than the sum of the contributions of parent employment, affiliate employment, and materials.

The estimates can be used to study the determinants of productivity growth and, in particular, distinguish between different sources of growth. For example, the recent mini-boom in productivity comes from a reallocation of output to more productive firms, not a general increase in productivity. The results also indicate that there is

⁴Griliches (1979) argues that even if such data existed they would not contain sufficient variation for estimation.

⁵This 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).

substantial heterogeneity in MNC productivity. In the time- and cross-sectional dimensions, MNCs' productivities differ widely depending on the countries in which their affiliates are located.

Finally, I quantify how tax policy affects MNC productivity by linking changes in the after-tax price of capital with embodied technical change. Embodiment means that new capital is more productive than old capital. The estimates imply that the parent's best practice technology is 66 percent above the average level of technology but that the affiliates' best is indistinguishably different from average. This means that there is an economically significant disadvantage for parent's operating the average capital good relative to the frontier one. This suggests that productivity can be increased by decreasing the average age of capital. Hence, changes in the after-tax price of capital can result in investment which translates directly into productivity growth.

2 Theoretical Model

When technical change is disembodied, the capital stock, K_t , is equal to the weighted sum of undepreciated capital from each vintage:⁶

$$K_t = I_t + (1 - \delta)I_{t-1} + \dots + (1 - \delta)^t I_0, \quad (1)$$

where I_t is investment in year t and δ is the constant rate of geometric depreciation. In this case, technical progress generates greater output regardless of whether the firm invests. When technical change is embodied in capital, the capital stock is computed by defining investment in terms of efficiency units, H_t :

$$H_t = \Phi_t I_t, \quad (2)$$

where Φ_t is the level of frontier technology in year t . The growth rate of Φ is the growth of rate of embodied technical change. In contrast to when technical change is disembodied, in this case, technical progress generates greater output only when the firm invests.

⁶The firm index i is suppressed to economize on notation except where essential.

The capital stock measured in efficiency units is equal to:

$$\begin{aligned} J_t &= H_t + (1 - \delta)H_{t-1} + \dots + (1 - \delta)^t H_0 \\ &= \Phi_t I_t + (1 - \delta)\Phi_{t-1}I_{t-1} + \dots + (1 - \delta)^t \Phi_0 I_0. \end{aligned} \quad (3)$$

The difference between K_t and J_t is given by the average embodied technical efficiency, Ψ_t , defined as the weighted average of the frontier efficiency levels of each past vintage of investment:

$$\begin{aligned} \Psi_t &= \frac{I_t}{K_t} \Phi_t + \frac{(1 - \delta)I_{t-1}}{K_t} \Phi_{t-1} + \frac{(1 - \delta)^2 I_{t-2}}{K_t} \Phi_{t-2} + \dots \\ &= \frac{J_t}{K_t}. \end{aligned} \quad (4)$$

The after-tax price of investment measured in units of I_t is P_t^I and, similarly, P_t^K is the price of using one unit of K_t for one period.⁷ Letting P_t^H and P_t^J denote the corresponding prices of investment and capital in efficiency units, I can using the accounting identities, $P_t^I I_t = P_t^H H_t$ and $P_t^K K_t = P_t^J J_t$, to express Φ_t and Ψ_t in terms of prices:

$$\Phi_t = \frac{P_t^I}{P_t^H}; \quad \Psi_t = \frac{P_t^K}{P_t^J}. \quad (5)$$

To this point it has been assumed that there is only a single capital good, but MNCs use different capital goods in each location where they operate.⁸ Specifically, the MNC uses a vector of quasi-fixed factors of production consisting of the parent and affiliates' beginning-of-period quality-adjusted capital, $\mathbf{J}_t = \{J_{jt}\}_{j=1}^n$, where j indexes the n locations of capital. The variable factors of production are labor, $\mathbf{L}_t = \{L_{jt}\}_{j=1}^n$ and materials, M_t . The firm produces gross output, Y , using a quasi-concave production function:

$$Y_t = F(\mathbf{J}_t, \mathbf{L}_t, M_t, t | \boldsymbol{\alpha}), \quad (6)$$

⁷To economize on notation, tax terms are suppressed. In the empirical work I incorporate data on the after-tax prices of investment.

⁸It is likely that capital is heterogeneous within each location, as well as across locations, but this has to be ignored because the data on MNCs do not detail different types of investment goods. 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.

where t is introduced as an argument to account for disembodied technical change; and α is a parameter vector describing the technical coefficients of production. According to this 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. Additional structure is imposed by assuming that affiliates' factor inputs are weakly separable from other inputs. In this case, the parent firm's inputs can be separated from the aggregates of the affiliates' inputs:

$$Y_t = F(J_{dt}, J_{ft}, L_{dt}, L_{ft}, M_t, t | \alpha), \quad (7)$$

where d and f index the domestic parent and aggregate foreign affiliate, respectively.

The logarithmic time derivative of equation (7) relates the growth rate of output and the share-weighted growth rates of quality-adjusted capital, labor, and materials:

$$\hat{Y}_t = \alpha_{L_d} \hat{L}_{dt} + \alpha_{L_f} \hat{L}_{ft} + \alpha_{J_d} \hat{J}_{dt} + \alpha_{J_f} \hat{J}_{ft} + \alpha_M \hat{M}_t + \lambda_t, \quad (8)$$

where hats over output and inputs denote their growth rates; λ_t is the rate of disembodied technical change in year t ; and, assuming perfect competition and constant returns to scale, the α 's denote the factor shares, S . For example, the capital shares are:

$$\alpha_{J_d} = \alpha_{K_d} = S_{K_d} = \frac{P_{dt}^J J_{dt}}{V_t} = \frac{P_{dt}^K K_{dt}}{V_t}; \quad \alpha_{J_f} = \alpha_{K_f} = S_{K_f} = \frac{P_{ft}^J J_{ft}}{V_t} = \frac{P_{ft}^K K_{ft}}{V_t}, \quad (9)$$

where V_t is the value of input and output.

Equation (8) is the theoretical basis for decomposing the sources of output growth, but it suffers from a practical drawback. In most datasets quality adjustment is unobserved. Hence to study the sources of growth, the share weighted growth rate of quality adjusted capital must be separated into quality unadjusted units, which are observable, and the growth rates of the two types of embodied technical change, which are unobservable:

$$\hat{Y}_t = \alpha_{L_d} \hat{L}_{dt} + \alpha_{L_f} \hat{L}_{ft} + \alpha_{K_d} \hat{K}_{dt} + \alpha_{K_f} \hat{K}_{ft} + \alpha_M \hat{M}_t + \alpha_{K_d} \psi_{dt} + \alpha_{K_f} \psi_{ft} + \lambda_t, \quad (10)$$

where ψ_{jt} is the growth rate of Ψ_{jt} . The terms $\alpha_{K_d}\psi_{dt}$ and $\alpha_{K_f}\psi_{ft}$ summarize quality change resulting from technology embodied in domestic and foreign capital input, respectively. Notice that when there is no disembodied technical change, $\lambda_t = 0$, technical change is entirely embodied.

Finally, the growth rate of output can be equated with the share weighted sum of the growth rates of inputs and the growth rate of total factor productivity, $T\hat{F}P_t$:

$$\hat{Y}_t = \alpha_{L_d}\hat{L}_{dt} + \alpha_{L_f}\hat{L}_{ft} + \alpha_{K_d}\hat{K}_{dt} + \alpha_{K_f}\hat{K}_{ft} + \alpha_M\hat{M}_t + T\hat{F}P_t. \quad (11)$$

In the empirical productivity literature $T\hat{F}P_t$ is typically interpreted as an estimate of the growth rate of disembodied technical change. However, in this model total factor productivity growth is composed of both embodied and disembodied improvements in productivity:

$$T\hat{F}P_t = \alpha_{K_d}\psi_{dt} + \alpha_{K_f}\psi_{ft} + \lambda_t. \quad (12)$$

While the growth rate of the average level of productivity, ψ_{jt} , is unobservable, it does depend on observables. Specifically, it is a function of current investment and the average level of productivity in the preceding year. For example, if a firm's capital stock is relatively new, current investment will have a modest impact on the growth rate of its average productivity. In contrast, investment by a firm with a relatively old capital stock will have a substantial impact on the growth rate of its average productivity. The elasticity of embodiment, ϵ_{jt} , which defines the percent difference between the current best practice technology and the average level of technology, formalizes the connection (see, Hulten 1992):

$$\begin{aligned} \psi_{jt} &= \frac{\Phi_{jt} - \Psi_{j,t-1}}{\Psi_{j,t-1}} \frac{I_{jt}}{K_{j,t-1}} \\ &= \epsilon_{jt} \frac{I_{jt}}{K_{j,t-1}}. \end{aligned} \quad (13)$$

Equations (12) and (13) define the growth in embodied technical change, $\hat{EP}_t$:

$$\begin{aligned}\hat{EP}_t &= \alpha_{K_d} \psi_{dt} + \alpha_{K_f} \psi_{ft} \\ &= \alpha_{K_d} \epsilon_{dt} \frac{I_{dt}}{K_{d,t-1}} + \alpha_{K_f} \epsilon_{ft} \frac{I_{ft}}{K_{f,t-1}}.\end{aligned}\tag{14}$$

According to this relationship, the growth in embodied technical change is a function of current investment, the factor shares, and the elasticities of embodiment. Given the investment-capital ratios, the production function parameters, and EP_t , this equation can be used to infer the value of the elasticity of embodiment.

The effect of investment on productivity is made explicit by rewriting equation (10) using equation (14):

$$\begin{aligned}\hat{Y}_t = & \alpha_{L_d} \hat{L}_{dt} + \alpha_{L_f} \hat{L}_{ft} + \alpha_{K_d} (1 + \epsilon_{dt}) \hat{K}_{dt} + \alpha_{K_f} (1 + \epsilon_{ft}) \hat{K}_{ft} + \alpha_M \hat{M}_t \\ & + \alpha_{K_d} \epsilon_{dt} \delta + \alpha_{K_f} \epsilon_{ft} \delta + \lambda_t,\end{aligned}\tag{15}$$

When capital is measured in unadjusted units the correct output elasticity for growth accounting has to be marked-up by the elasticity of embodiment. Estimates of the parameters of the production technology ignore this additional output growth from capital because $\alpha_j \psi_j$ is in the residual. I will use an indirect technique, described below, to infer ϵ_j and thereby arrive at the true output elasticity of capital.

The link between tax policy and embodied technical change is completed by specifying the relationship between the after-tax price of capital and investment. In the empirical investment literature this is done using marginal q , defined as the ratio of the marginal after-tax cost of investment, including adjustment costs, to its market price:

$$q_{jt} = \frac{C_{I_{jt}} + P_{jt}^I}{P_{jt}^I}.\tag{16}$$

where $C_{I_{jt}}$ is the marginal adjustment cost for investment in location j . I assume that marginal adjustment costs are linear, $C_{I_{jt}} = \beta_j \left(\frac{I_{jt}}{K_{j,t-1}} \right) + v_t$, where β_j are the parameters describing the technical coefficients of adjusting the capital stock and v_t is a structural disturbance to the adjustment cost technology ($E_t(v_t) = 0$, $E_t(v_t^2) = \sigma_v^2$). Provided the firm's net revenue and adjustment cost functions are linear homogeneous, and the

firm operates in perfectly competitive markets, Hayashi and Inoue (1991) and Chirinko (1993b) prove that Tobin's average Q — defined as the ratio of the market value of the firm to the replacement cost of its capital stock — can be substituted for the marginal q 's in equation (16). Then the following investment equation can be estimated:

$$Q_t = \sum_{j=1}^n \frac{K_{jt}}{K_t} q_{jt} = \beta_0 + \beta_d \frac{I_d}{K_{d,t-1}} + \beta_f \frac{I_f}{K_{f,t-1}} + v_t, \quad (17)$$

where β_0 is introduced as an intercept. Although the focus of this paper is not on investment behavior, I estimate the adjustment costs parameters in equation (17) for the firms in the sample because they govern how responsive investment is to changes in average Q . If the adjustment costs are large (large β 's), changes in Q — resulting from, e.g., changes in capital income tax policy — will translate into small increases in productivity, regardless of the magnitude of the elasticity of embodiment.

3 Empirical Methodology

The MNC's production technology is likely to be a complicated function, which argues for using a flexible functional form to approximate it. However, estimates of output elasticities are usually qualitatively unaffected if a first-order approximation to the technology is used (Griliches and Mairesse 1995). Hence the Cobb-Douglas is generally used for growth accounting:

$$y_t = \alpha_{L_d} l_{dt} + \alpha_{L_f} l_{ft} + \alpha_{K_d} k_{dt} + \alpha_{K_f} k_{ft} + \alpha_M m_t + \sum_{t=1}^T \alpha_t D_t + u_t, \quad (18)$$

where lowercase letters represent the logarithms of variables; D_t are year dummy variables, where T is the total number of years in the panel. Total factor productivity is the sum of the dummy variables and the residual, u_t (i.e. the residual growth rate of output not attributable to the factor inputs).

The problem in consistently estimating the parameters in equation (18) is that inputs in place are correlated with u_t . This occurs because current input choices are a function of current and expected future realizations technology shocks that are unobserved by the econometrician. Any econometric procedure that fails to account for the

endogeneity will yield biased estimates of the input coefficients. The bias can be severe for the more variable inputs because they are more highly correlated with current realizations of technical change. But the bias will also occur for quasi-fixed inputs because demand for them depends on expected future technology so those in place are also correlated with u_t . In the results, the estimates using ordinary least square (OLS) are compared to those from the semiparametric procedure introduced by Olley and Pakes (1996) that corrects for the bias (see Cummins and Hassett (1996) for details on the estimation procedure).

Using the unbiased estimates, total factor productivity for each firm, TFP_{it} , where the firm index i is introduced, is calculated as:

$$\begin{aligned} TFP_{it} &= Y_{it} - \exp(\alpha_{L_d} l_{idt} + \alpha_{L_f} l_{ift} + \alpha_{K_d} k_{idt} + \alpha_{K_f} k_{ift} + \alpha_M m_{it}) \\ &= Y_{it} - Z_{it}. \end{aligned} \quad (19)$$

Aggregate TFP_t is the weighted average of firm-level TFP_{it} :

$$TFP_t = \sum_{i=1}^N TFP_{it} \frac{Y_{it}}{Y_t} \quad \text{where } Y_t \equiv \sum_{i=1}^N Y_{it}, \quad (20)$$

and N is the number of MNCs. Aggregate TFP_t can be decomposed as the sum of unweighted aggregate productivity, $\overline{TFP}_t$, and the sample covariance between TFP_t and output:

$$TFP_t = \overline{TFP}_t + \sum_{i=1}^N \Delta \frac{Y_{it}}{Y_t} \Delta TFP_{it}. \quad (21)$$

The larger is the covariance, the higher the share of output that goes to more productive firms. This decomposition can be used to answer whether productivity changes result from changes in average productivity or a reallocation of inputs to more productive firms.

Embodied technical change can be distinguished from disembodied technical change using the coefficient estimates on the year dummy variables:

$$EP_{it} = TFP_{it} - \exp \left(\sum_{t=1}^T \alpha_t D_t \right). \quad (22)$$

This value can be used to calculate $E\hat{P}_{it}$. Then when a disturbance is appended to equation (14), the regression of $E\hat{P}_{it}$ on $\alpha_j I_{jt}/K_{jt}$ provides estimates of ϵ_{jt} . This is a purely statistical relationship since investment is likely to be endogenous, so it is only used to gain a sense of the magnitude of the mean elasticity of embodiment across firms and over the sample period.

4 Data

The production function is estimated using a firm-level panel dataset constructed from several sources. A detailed description of how the variables are constructed is contained in appendix A. 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 reports only a limited set of information on the foreign operations of MNCs: capital expenditures, tangible fixed assets, operating income, depreciation, and sales. The data are recorded for seven years at a time. I combine three seven-year panels to obtain a dataset extending from 1980 to 1995.⁹ The tax parameters are updated and expanded from Cummins, Hassett, and Hubbard (1995). There are about 200 parent and affiliates with complete data for at least one year.

As discussed in the presentation of the theoretical model, MNCs vary in the number of different locations in which they operate. When this is the case, it makes the specification of the production technology problematic. Consider how to estimate the parameters of the Cobb-Douglas production function when, e.g., some MNCs operate in ten foreign countries while the rest operate in a single foreign country. The parameters for the nine countries in which some firms in the sample have no operations are unidentified. Indeed, it would be necessary to formulate a model to explain why firms locate in different numbers of countries. To enable comparison among MNCs, I assume that all the MNCs' foreign affiliates can be aggregated into a single foreign affiliate. This is a strong assumption that is likely invalid (see, e.g., Cummins and Hassett 1996), but the

⁹Due to differences in accounting reporting requirements prior to 1980, the panel begins in 1980.

bias is unlikely to materially affect estimated output elasticities (Griliches 1979), which are the focus for growth accounting. The individual countries for which Compustat reports affiliate data are Australia, Canada, France, Germany, Japan, and the United Kingdom.¹⁰ When MNCs report operations for more than one country I aggregate them and denote the affiliates' country as 'multiple'. These six countries receive the majority of US MNCs' FDI.

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. I 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 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, I 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 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.

Summary statistics for the data used in estimation are given in table 1. The number of MNCs in the sample increases from 28 firms in 1981 to 91 firms in 1995. The total number of observations is 1012. The sample variables are MNC's gross output (Y), parent and affiliate capital (K_d and K_f) and labor (L_d and L_f), and materials (M). Included in the table are the mean, medians, and standard deviations of the variables. The sample statistics indicate that there is wide variation in the size of firms and the composition of their capital stocks. Despite entry into the sample, the sample statistics are broadly similar over time. The exceptions to this are the large jumps in both parent and affiliate mean capital stocks in 1990 and 1991. These increases were not accompanied by increases in other factor inputs

¹⁰Mexico and Brazil are also reported but are excluded.

5 Empirical Results

5.1 Production Function Estimation

Table 1 presents the estimates of the parameters of the MNC's Cobb-Douglas production function. Standard errors on the estimates are in parentheses. (All of the parameter estimates are statistically significant from zero at better than the one percent level.) In each of the specifications year effects are estimated but not reported. For comparison to the literature both value-added and gross output production functions are estimated. In the first two columns the dependent variable is value-added, and in the last two gross output is used.¹¹ The former is the more common specification because government statistical agencies report a variety of measures of real value-added (e.g., GDP), but not price and quantity data on gross output and intermediate inputs. Some form of separability is required to derive the value-added specification — perfect substitutability or complementarity of materials with other factors of production suffices — so the gross output specification is preferable for its generality. In theory the parameter estimates in the gross output specification equal those from the value-added specification multiplied by $(1 - \alpha_M)$. A comparison between the results shows that this condition is not satisfied suggesting that the value-added specification is misspecified. This misspecification could result in mistaken inference about the sources of growth (see, Bruno 1984; and the comments by Baily 1986; Grubb 1986). I concentrate, then, on the results in columns three and four.

Comparing the estimates from OLS in column three to the ones from the semiparametric estimator in column four shows that the OLS estimates of the share of domestic capital are biased upward and the estimates of the affiliate inputs are biased downward. In terms of accounting for growth, the OLS estimates would imply a larger contribution from parent's capital and smaller contributions from affiliates' factors. The implied returns to scale in column three are 1.01 and 0.99 in column four. The estimated parameters then are approximately equal to their factor shares when perfect competition

¹¹There were 16 values of value-added, defined as gross output less materials, that were negative and had to be deleted. Thus the number of observations in columns one and two is 16 less than in three and four.

is assumed. The estimates of the parent's employment share and materials are virtually identical using either estimator. This is somewhat surprising since variable factors are more likely to be correlated with current realizations of shocks. However, the year effects may capture these shocks in which case the estimates of the variable factors would be unaffected by using the semiparametric technique. In column four, the total share of parent's inputs is about 0.41 and the total share of affiliate's inputs is about 0.16. Notably, the parent's capital-labor ratio is about 0.45, while the affiliates capital-labor ratio is about 1.1. The affiliates then seem to be much more capital intensive.

5.2 Sources of MNC Growth

Table 3 contains the aggregate indexes of factor inputs. Each index is calculated as the annual average of the firm-level factor inputs using gross output shares as weights (i.e., the same way aggregate TFP is defined in equation 20). The first year of the sample, 1981, is used as the base of the index. Relative to capital inputs there is little growth in labor or material inputs. The growth in affiliate capital is largest, increasing at more than 14 percent annually over the entire period. This increase, however, is insufficient to understand FDI's contribution to growth since it is unweighted by its share in output.

To calculate average annual share-weighted growth rates, the parameter estimates in column four of table 1 are used as shares. In the bottom panel of the table the average annual growth rates are presented for the whole period and three five-year sub-periods. Over the entire period the share-weighted growth rates of capital are the largest contributors to growth. While the parents' capital growth rate contributes the most to growth, the affiliates' capital contributes more than the sum of all the other factors. As emphasized by Hulten (1978), growth in intermediate inputs, i.e. materials, is partly due to technical change. Thus even the contribution of materials to growth may reflect improvements in the quality of capital. Based on these results, MNCs' capital is the most important source of growth, with FDI nearly as important as domestic capital growth. This pattern is broadly consistent in the three sub-periods, although the contributions of capital are smaller recently.

In table 4, TFP and its components are presented. The aggregate productivity indexes are calculated as the annual average of the firm-level productivity estimates from

the semiparametric specification in column four of table 1. The weighted index in column one uses firm-level gross output shares as weights (see equation 20). The percent of embodied and disembodied technical change in columns two and three are their shares in TFP, calculated as the ratio of embodied or disembodied technical change (from equation 22) to TFP. The unweighted index of TFP is in column four. The percent of embodied and disembodied technical change in unweighted TFP are in columns five and six. Finally, the difference between the weighted and unweighted indexes is $Cov(TFP_{it}, Y_{it})$, the sample covariance between TFP and gross output.

Both weighted and unweighted TFP have declined over the sample period. Thus $T\hat{F}P$ has actually retarded growth. This is a somewhat usual result, as TFP is often the single most important contributor to growth. For example, in the original growth accounting study, Solow (1957) found that technical change accounted for the greatest share of growth; Hulten (1992) found that TFP was the largest contributor over the period 1949–83. Nevertheless, there are a number of studies which use micro data that find that productivity has declined, even in industries in which this result might seem contrary to conventional wisdom. For example, Olley and Pakes (1996) find that weighted TFP in the telecommunications industry declined by three percent from 1974 to 1987; unweighted productivity declined by 34 percent over the same period (for a survey of other studies with similar results see, Nadiri and Prucha 1997). Disembodied change accounts for more than 70 percent of TFP. This finding is similar to that in Hulten (1992) in which disembodied productivity accounted for about 80 percent of TFP. Embodied change accounts for a declining share of TFP in the 1980s but sharply rises in the 1990s. The unweighted TFP index is also declining. In the unweighted index, however, the share of disembodied technical change is increasing consistently through the sample period.

The final column is the difference between the two indexes, or the sample covariance between output and productivity. When this covariance is positive the share of output that goes to more productive firms is higher and thus aggregate productivity is higher. Until 1992 the covariance is relatively small. After 1992 the data indicate that there was a substantial reallocation of output toward more productive firms. This could result from reallocating factor inputs toward more productive firms or from using the existing factor inputs more efficiently in more productive firms. Unfortunately, the

econometric approach is not rich enough to disentangle the contributions of these two alternatives.

Figures 1 and 2 illustrate this boom. The first plots the two indexes from table 4 and the second plots the growth rates of the indexes. The boom in productivity is quite pronounced. In addition, the other striking feature is the drop in productivity in 1986. A complete analysis of these changes is beyond the scope of this paper and, indeed, would require a rather complicated dynamic general equilibrium model. However, it is possible to speculate on the sources of these two productivity changes. First, the boom in productivity coincides with NAFTA, suggesting that productivity may be associated with freer trade. I investigate this possibility in figures 3 and 4. Figure 3 depicts the productivity indexes for firms with Canadian affiliates. The boom is even more dramatic for these MNCs than for MNCs overall. In addition, comparison of the weighted index to the unweighted index shows that the boom was caused by a dramatic reallocation of output from less productive to more productive firms. Figure 4 depicts the productivity indexes for firms with affiliates in countries besides Canada. Productivity in these MNCs has been declining steadily since the late-1980s. There is also little difference between the weighted and unweighted indexes, indicating that the productivity drop results from a decline in average productivity. The second feature of these figures, the drop in productivity in 1986, is intriguing as it may be correlated with the increase in the after-tax cost of equipment capital from the Tax Reform Act of 1986. I investigate this possibility more formally and generally in table 6 using regression analysis.

Table 5 compares aggregate TFP by the location of the MNCs' affiliates. Most of the MNCs in the sample report data for only a single foreign affiliate but about a quarter of the MNCs report affiliate data in multiple countries. These firms are in the row labeled 'multiple' in the table. The format of the table is the same as in table 4 except instead of comparing productivity over time, relative to a base year, the table compares productivity among MNCs, relative to the productivity of the MNCs with Canadian affiliates. The weighted TFP index in the first column is calculated as the affiliate country average of the firm-level productivity estimates from the semiparametric specification in column four of table 1. Only the MNCs with Japanese affiliates have higher weighted TFP than those in Canada. Perhaps surprisingly, Australia and the United Kingdom have the lowest productivity. There is substantial heterogeneity in the percent of disembodied

versus embodied technical change. In Australia there is almost no embodied technical change, while it accounts for about 21 percent of productivity in Japan. The unweighted TFP index is in column four. Relative to Canadian affiliates, no other countries' affiliates have greater unweighted productivity. Finally, in column seven, the covariance between TFP and output is usually positive. Thus average productivity is greater for the MNCs with affiliates in these countries because of a reallocation of output from less to more productive MNCs. The exceptions are Australia and the UK where the covariance is negative, but close to zero. In these countries, changes in average productivity, not a reallocation of output from less to more productive firms, drives productivity growth.

5.3 Linking Taxation, Investment, and Productivity

The estimates in table 6 provide the basis for exploring the connection between changes in the after-tax price of capital and productivity. According to the model, technical change is embodied in new capital, so tax policy can affect productivity directly through investment by changing the after-tax price of capital. The connection is made using equation (14), which translates investment into productivity, and equation (17), which translates changes in the value of a marginal unit of capital into investment. Both adjustment costs and the elasticity of embodiment are important in linking changes in policy with changes in productivity. When either the elasticity of embodiment is small or adjustment costs are large, changes in tax policy can have only a minor impact on productivity. For example, consider a firm with a relatively old capital stock and, hence, a large elasticity of embodiment. If the firm faces high adjustment costs, changes in the cost of capital will have a small effect on investment and productivity. However, if adjustment costs are modest, the same changes will have a large effect on investment and productivity. In contrast, there is little room for even large investment responses to have an effect on productivity in a firm with a relatively new capital stock since the elasticity of embodiment is small.

The first two columns present OLS estimates of the adjustment cost parameters from the investment equation (17). This approach uses average Q as the dependent variable when estimating the adjustment costs parameters. This approach is novel; only Barnett and Sakellaris (1996) have estimated a similar investment equation. There

are a number of advantages to this specification. First, measurement error in average Q is more severe than is measurement error in the investment-capital ratios. Since measurement error in the dependent variable does not affect the parameter estimates, the resulting estimates are likely to be less biased compared to those when Q is a regressor. Second, the extension of the usual single capital good investment equation to the case of multiple capital goods indexed by location is natural in this specification; the investment-capital ratios of additional locations are just included as additional regressors.¹²

In the first column the dependent variable is tax-adjusted average Q (for details on the construction of this variable, see Cummins et al. 1994). The parameter estimates are statistically significant and imply marginal adjustment costs of investment that are small compared to many studies (see, e.g., Chirinko 1993a). The estimates for the parent's adjustment costs are similar to those obtained by Cummins et al. (1994) for US firms in the "natural experiment" years using the usual empirical approach to estimate the Q model. The estimates for the affiliates are similar to those for affiliates in Altshuler and Cummins (1997) and Cummins and Hubbard (1995). The number of observations drops because some of the data necessary to calculate tax-adjusted Q are missing. In the second column the dependent variable is real Q constructed by Cummins et al. (1997) from securities analysts' earnings expectations. This measure has theoretical and empirical appeal since it relies on professionals to forecast the value of the firm, rather than on market data which tend to be quite noisy measures of fundamentals. The parameter estimates are both statistically significant and imply lower adjustment costs for parent investment and about the same costs for affiliate investment. There are only 291 observations because real Q is frequently missing. These estimates suggest that adjustment costs are relatively modest, which at least opens the possibility for tax policy to affect productivity.

In the third column, I use equation (14) to explore the connection between investment and the growth in embodied productivity. OLS is used to estimate the relationship by appending a stochastic disturbance to the equation. The disturbance is assumed to

¹²Cummins and Dey (1997) show that a more general model with heterogeneous capital goods is preferable to this approach. However, their econometric approach is considerably more complex. Since the focus of this paper is not on investment behavior per se, I adopt this more transparent specification. For the same reason, I ignore a number of important econometric issues involved in estimating even this simpler investment equation.

be uncorrelated with the regressors.¹³ As a result, the coefficient estimates must be treated with caution. The dependent variable is the growth rate of embodied productivity, defined in equation (22), and the regressors are the investment-capital ratios multiplied by their estimated capital shares, $\alpha_{K_d} = 0.131$ and $\alpha_{K_f} = 0.085$.¹⁴ The number of observations is only 352 for two reasons: once lagged embodied technical change is needed to construct the growth rate; and observations were deleted if the estimated embodied productivity was negative – which is empirically possible given the decomposition of TFP into embodied and disembodied components, but theoretically impossible. The estimate of the elasticity of embodiment is 0.664 and statistically significant at the ten percent level. The estimate of the affiliate's average elasticity of embodiment is -0.150, which is nonsensical, but it is statistically insignificant from zero.¹⁵ Although there are a number of important caveats in interpreting these results, they imply that the best practice technology is 66 percent above the average level in parents, but indistinguishably different from average in affiliates. While there is no data on the average age of the parent's and affiliate's capital stock, it is likely that the parent's stock is older. Hence, despite the numerous assumptions underlying this approach the results are at least sensible.

The size of these elasticities affect the contribution of capital to growth. Recall from equation (15) that the true contribution of quality unadjusted capital is marked up by the elasticity of embodiment. This implies that the true output elasticity for parent capital is 0.22 instead of 0.13, while the output elasticity of affiliate capital is unaffected. Using this value to recalculate the annual share-weighted growth rate of parent capital in the bottom panel of table 3 increases its contribution to growth from

¹³It would be preferable to relax the assumption that the disturbance is orthogonal to the regressors and use an instrumental variable estimator such as GMM. However, such an approach is infeasible because the lagged (period $t - 2$ and $t - 3$) dependent variables that are suitable instruments are missing too frequently.

¹⁴All the variables in the regression are “generated” regressors. The dependent variable is the growth rate of a residual from the estimation of the production function. Measurement error in the dependent variable, however, does not affect the coefficient estimates. The regressors are “generated” because the capital shares are estimated. For my purposes, however, this is unimportant since Pagan (1984) shows that the OLS estimator provides asymptotic t -statistics that are valid for the hypothesis test that the coefficient estimate on the generated regressor is zero.

¹⁵The OLS estimates of these elasticities using the growth rate of the aggregate index of embodied technical change and the growth rate of the indexes of parent and affiliate capital multiplied by their estimated capital shares are, 2.69 and -1.76, respectively. Neither estimate is statistically significant as there are only 14 observations.

1.49 to 2.48 percent. In studies that ignore quality adjustment this additional contribution to growth is spuriously attributed to TFP not capital. These results highlight that investment affects output growth through two channels, increasing both quality unadjusted capital and embodied productivity. As is clear from comparing the parent's and affiliate's elasticity of embodiment, this effect diminishes as the average age of the capital falls. Hence, increases in embodied productivity have only a transitory effect, raising the level of output but not permanently changing its growth rate.

6 Conclusion

The growth accounting for US MNCs indicates that there is broad similarity in some dimensions but significant differences in others. Across firms, parent investment and FDI — in spite of capitals' relatively modest share in output — are the most important sources of MNC growth. Indeed, FDI is nearly as important as domestic investment and contributes more to growth than the sum of the contributions of parent and affiliate employment, and materials.

Productivity declined throughout the 1980s and has recovered in the 1990s. This general trend masks two very different experiences. MNCs with Canadian affiliates have had a productivity boom since 1992, while MNCs with affiliates elsewhere have continued their slide. There are wide cross-sectional differences among MNCs depending on where their affiliates operate. The MNCs with affiliates in the UK are nearly the least productive.

A number of previous studies have highlighted the important role played by capital in growth accounting when technical progress is embodied. However, these studies concluded that embodiment was empirically unimportant. For example, Hulten (1992) echoed Denison (1964) by finding that changes in the age structure of capital have had little effect on output growth. In contrast, in this study, embodiment is empirically important. The already large contribution of parent capital to growth are marked-up significantly because of embodied technical change. Since the parent's elasticity of embodiment is large and adjustment costs of investment are small, changes in the after-tax price of capital result in robust investment which translates directly into productivity

gains. This connection at least suggests the possibility that tax incentives for capital increase productivity and growth.

A 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. 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.¹⁶ The depreciation rate of parent and affiliate capital is assumed identical and calculated using depreciation rates in Hulten and Wyckoff (1981). Net investment is the change in each capital stock. Gross investment is the sum of net investment and depreciation.

Total labor input is defined as total employees.¹⁷ I use an auxiliary dataset to construct the parent's and affiliates' labor input from total employees. The US Bureau of Economic Analysis (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, I construct the percent of total employment accounted for by the parent and its affiliates by industry. I 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 SIC industry codes. Typically, the BEA industry classification corresponds to a two- or three-digit SIC code but in some cases it corresponds to a one- or four-digit code. Parent and affiliate employment 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.¹⁸

¹⁶Major capital stock changes are deleted to eliminate clear discontinuities in the identity of the firm or measurement error. Second, the geographic segment file provides a footnote if the data reflect the results of a merger or acquisition. Firms recording this footnote are deleted.

¹⁷Labor and related expense is not reported frequently enough to be empirically useful.

¹⁸I checked the accuracy of this method by comparing the employee numbers to those from the companies' annual reports. I picked a random sample of 20 MNCs from the sample and found that in most cases our method gave numbers within ten percent of those reported in their 1993 annual report.

Material input is calculated by separating labor expense from total expense, defined as the sum of cost of goods sold, and, when reported, selling, general, and administrative expense. Total labor expense is calculated as the sectoral average labor cost per employee multiplied by total employees and deflated by the price index for total compensation. The average sectoral labor cost is computed using 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 BLS began this survey in 1986 so the values for earlier years are obtained by extrapolating backward using the sector-level employment cost index. I assume a 2040 hour work year to calculate the annual salary. Then materials are calculated as total expense less labor expense. Value added is gross output less materials.

The construction of average Q and real Q are complicated and are both described in detail in Cummins, Hassett, and Oliner (1997).

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).¹⁹ The price of capital and output goods are, respectively, the property, plant and equipment deflator (PPE) and the GDP deflator of the US. All capital and investment variables are deflated by the US PPE deflator and output is deflated by the US GDP deflator.

¹⁹Ken McKenzie kindly supplied some of the Canadian tax parameters.

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Table 1: Means, Medians, and Standard Deviations of Selected Sample Variables

Year	Number of Firms	Gross Output	Parent Employees	Affiliate Employees	Parent Capital	Affiliate Capital	Materials
1981	28	441.1 (82.3) [1475.6]	2334.4 (661.0) [7013.2]	530.1 (206.0) [1430.1]	304.2 (43.8) [758.1]	39.0 (10.8) [97.0]	330.8 (30.7) [1316.9]
1982	28	338.1 (67.8) [1027.4]	2153.3 (575.5) [6257.6]	465.2 (162.5) [1276.1]	307.6 (45.2) [748.9]	29.1 (10.9) [58.4]	234.8 (27.6) [876.4]
1983	34	298.9 (45.1) [1023.0]	2179.1 (306.0) [7566.6]	474.5 (162.5) [1544.1]	287.1 (31.1) [783.3]	27.5 (7.8) [63.5]	203.2 (19.7) [840.4]
1984	45	373.9 (63.8) [997.1]	2538.9 (458.0) [7072.4]	546.0 (190.0) [1308.9]	461.7 (41.3) [1207.6]	63.9 (9.4) [135.2]	237.9 (30.9) [813.9]
1985	46	458.6 (81.9) [1105.9]	3974.5 (762.0) [10233.]	889.6 (290.5) [1929.0]	637.4 (52.6) [2338.9]	69.0 (10.8) [156.6]	278.3 (37.1) [869.6]
1986	55	528.0 (88.7) [1248.3]	4462.2 (800.0) [11082.]	1116.2 (255.0) [2672.3]	385.6 (69.4) [791.4]	58.4 (10.7) [122.7]	350.0 (46.6) [957.9]
1987	68	492.5 (73.8) [1280.5]	3369.6 (624.5) [9429.0]	818.8 (208.5) [2022.3]	394.2 (38.9) [840.5]	77.9 (11.2) [199.7]	337.5 (41.0) [1015.7]
1988	79	641.4 (67.9) [1890.8]	4565.7 (440.0) [13583.]	1090.7 (205.0) [3100.1]	415.3 (39.7) [989.2]	88.1 (9.9) [227.5]	448.4 (37.4) [1528.6]
1989	77	662.9 (77.3) [1967.1]	4734.5 (434.0) [13840.]	1210.3 (200.0) [3439.8]	374.1 (45.9) [740.9]	97.5 (10.5) [247.3]	460.6 (46.3) [1575.1]
1990	88	630.9 (64.1) [1862.1]	4122.1 (463.0) [13596.]	1116.3 (213.0) [3331.9]	638.1 (46.0) [2499.2]	160.1 (13.1) [571.9]	425.8 (36.0) [1451.5]
1991	90	654.6 (73.9) [1830.1]	3611.2 (460.5) [11295.]	1334.5 (199.0) [4608.1]	815.8 (46.2) [2743.0]	171.8 (12.0) [570.7]	453.2 (39.4) [1446.2]
1992	90	630.4 (92.4) [1721.0]	4161.7 (479.5) [14211.]	664.8 (176.0) [1187.8]	883.3 (64.9) [2971.5]	158.9 (13.0) [507.0]	439.3 (49.3) [1381.8]
1993	90	736.5 (119.9) [1959.0]	3857.9 (684.0) [12527.]	1039.5 (223.0) [2922.5]	956.9 (91.2) [3311.0]	169.7 (16.3) [537.6]	535.8 (66.0) [1634.9]
1994	103	602.4 (95.4) [1819.5]	3047.2 (492.0) [11438.]	821.9 (167.0) [2679.3]	883.5 (83.0) [3273.2]	137.0 (12.0) [492.8]	443.6 (45.7) [1537.8]
1995	91	696.2 (92.22) [1976.5]	3340.9 (492.0) [12234.]	918.4 (173.0) [2867.7]	938.6 (96.6) [3266.5]	154.4 (16.4) [526.9]	520.5 (50.3) [1669.7]
Total	1012	589.9 (78.8) [1692.2]	3679.9 (532.0) [11745.]	934.7 (200.0) [2813.8]	650.4 (58.3) [2363.7]	117.7 (11.9) [413.2]	413.5 (40.2) [1378.5]

Variables are in millions of 1987 US dollars, except employees which is in units. Medians of the variables are in parentheses below the means. Standard deviations of the variables are in square brackets below the means.

Table 2: Cobb-Douglas Production Function Parameter Estimates

Parameter	Value-Added		Gross Output	
	OLS (1)	Semi-Parametric (2)	OLS (3)	Semi-Parametric (4)
α_{L_d}	0.602 (0.031)	0.611 (0.033)	0.288 (0.018)	0.281 (0.019)
α_{L_f}	0.112 (0.028)	0.102 (0.029)	0.065 (0.016)	0.074 (0.017)
α_{K_d}	0.259 (0.018)	0.207 (0.023)	0.171 (0.011)	0.131 (0.012)
α_{K_f}	0.055 (0.013)	0.041 (0.024)	0.058 (0.008)	0.085 (0.013)
α_M	—	—	0.427 (0.010)	0.423 (0.011)
Year Effects	Yes	Yes	Yes	Yes
Observations	996	996	1012	1012

The dependent variable in columns one and two is value-added. The dependent variable in columns three and four is gross output. Standard errors on parameter estimates are in parentheses. The semiparametric estimator is described in the text and in detail in Cummins and Hassett (1996).

Table 3: Sources of Growth: Aggregate Factor Input Indexes

Year	Parent Labor	Affiliate Labor	Parent Capital	Affiliate Capital	Materials
1981	1.00	1.00	1.00	1.00	1.00
1982	0.82	0.82	0.90	0.94	0.61
1983	1.09	1.09	0.99	1.17	0.65
1984	0.83	0.77	1.20	1.62	0.51
1985	0.99	0.95	2.04	2.09	0.50
1986	1.13	1.36	1.35	1.82	0.56
1987	1.04	1.13	1.42	2.30	0.64
1988	1.72	1.93	2.00	3.64	1.07
1989	1.77	2.16	1.89	4.11	1.11
1990	1.71	2.08	3.33	6.85	1.01
1991	1.36	2.69	3.87	7.37	0.97
1992	1.66	0.63	4.02	6.44	0.91
1993	1.28	1.59	4.07	5.93	1.05
1994	1.27	1.57	4.38	5.83	1.10
1995	1.27	1.57	4.54	6.43	1.13
Average annual share-weighted growth rates (in percent)					
1981-95	0.48	0.24	1.49	1.21	0.37
1981-85	-0.06	-0.09	2.56	1.72	-6.76
1986-90	3.11	0.84	3.32	3.34	6.73
1991-95	-0.50	-0.93	0.53	-0.29	1.67

Each aggregate index is calculated as the annual average of the firm-level factor inputs using gross output shares as weights. Average annual share-weighted growth rates use the estimates in column four of table 1 as shares.

Table 4: Sources of Growth: Aggregate Total Factor Productivity Indexes

Year	Weighted TFP Index	Percent Disembodied	Percent Embodied	Unweighted TFP Index	Percent Disembodied	Percent Embodied	$Cov(TFP_{it}, Y_{it})$
1981	1.00	78.3	21.7	0.89	87.8	12.2	0.11
1982	0.91	79.7	20.3	0.86	84.3	15.7	0.05
1983	0.86	84.2	15.8	0.81	88.9	11.1	0.04
1984	0.86	85.0	15.0	0.84	87.6	12.4	0.03
1985	0.85	86.4	13.6	0.83	88.1	11.9	0.02
1986	0.78	82.0	18.0	0.78	82.4	17.6	0.00
1987	0.81	87.8	12.2	0.77	93.0	7.0	0.05
1988	0.82	89.2	10.8	0.80	91.2	8.8	0.02
1989	0.79	89.7	10.3	0.76	93.1	6.9	0.03
1990	0.78	89.2	10.8	0.76	91.4	8.6	0.02
1991	0.76	88.1	11.9	0.75	89.4	10.6	0.01
1992	0.77	92.4	7.6	0.80	88.9	11.1	-0.03
1993	0.87	81.3	18.7	0.78	90.2	9.8	0.09
1994	0.89	74.4	25.6	0.72	91.6	8.4	0.17
1995	0.91	72.8	27.2	0.72	92.6	7.4	0.20

The aggregate productivity index is calculated as the annual average of the firm-level productivity estimates from the semiparametric specification in column four of table 1. The weighted index uses firm-level gross output shares as weights. The percent of disembodied technical change is the share of productivity attributable to year dummy variables in TFP. The percent of embodied technical change is the share of productivity not attributable to year effects in TFP. The difference between the weighted and unweighted indexes is $Cov(TFP_{it}, Y_{it})$, the sample covariance between TFP and gross output.

Table 5: Aggregate Total Factor Productivity: Cross-Sectional Comparison

Affiliate Country	Weighted TFP Index	Percent Disembodied	Percent Embodied	Unweighted TFP Index	Percent Disembodied	Percent Embodied	$Cov(TFP_{it}, Y_{it})$
Australia	0.83	99.8	0.2	0.84	99.2	0.8	-0.01
Canada	1.00	82.8	17.2	0.96	86.9	13.1	0.04
France	0.94	86.3	13.7	0.79	101.4	-1.4	0.14
Germany	0.86	95.0	5.0	0.85	97.2	2.8	0.01
Japan	1.03	79.2	20.8	0.88	91.6	8.4	0.15
United Kingdom	0.84	96.9	3.1	0.88	94.3	5.7	-0.04
Multiple	0.99	83.5	16.5	0.92	91.0	9.0	0.07

The aggregate productivity index is calculated as the affiliate country average of the firm-level productivity estimates from the semiparametric specification in column four of table 1. Canada is the base of the index. The weighted index uses firm-level gross output shares as weights. The percent of disembodied technical change is the share of productivity attributable to year dummy variables in TFP. The percent of embodied technical change is the share of productivity not attributable to year effects in TFP. The difference between the weighted and unweighted indexes is $Cov(TFP_{it}, Y_{it})$, the sample covariance between TFP and gross output.

Table 6: Investment and Embodied Technical Change: Estimates of Adjustment Cost Parameters and the Elasticities of Embodiment

Parameter	Investment Equation		Embodiment Equation
	(1)	(2)	(3)
β_{K_d}	4.40 (0.511)	3.39 (0.811)	—
β_{K_f}	1.67 (0.440)	1.70 (0.642)	—
ϵ_{K_d}	—	—	0.664 (0.381)
ϵ_{K_f}	—	—	-0.150 (0.182)
Observations	742	291	358

The investment relationship estimated is defined by equation 17. The embodiment relationship estimated is defined by equation 14. The dependent variable in column one is tax-adjusted Q_{it} . The dependent variable in column two is real Q_{it} . The dependent variable in column three is the growth of embodied technical change, EP_{it} , defined as the growth in the part of TFP not attributable to year effects. Standard errors on parameter estimates are in parentheses.

Figure 1: Aggregate Total Factor Productivity Indexes

Figure 2: Growth Rates of Weighted and Unweighted Total Factor Productivity

Figure 3: Aggregate Total Factor Productivity Indexes: Canadian Affiliates

Figure 4: Aggregate Total Factor Productivity Indexes: Non-Canadian Affiliates