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9

Taxation and the Sources of Growth
Estimates from U.S. Multinational Corporations

Jason G. Cummins

9.1 Introduction

Numerous careful studies of productivity have been made at the firm level (for surveys, see Mairesse and Sassenou 1991; Griliches and Mairesse 1995). None of these studies, however, focus on U.S. multinational corporations (MNCs) despite their important role in the global economy.[1] In this study, I fill that gap by estimating the parameters of the MNC's production technology and using them to study the sources of firm growth. This exercise is only a first step, albeit a necessary one, toward better understanding the effects of tax policy in an increasingly integrated global economy. It certainly is not sufficient because it ignores the effect of tax policy on the wider economy in general and on solely domestic firms in particular.

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. However, in this model tax changes cannot affect total factor productivity (TFP) directly because improvements in productivity are disembodied (i.e., technical change arrives as manna

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1. Many studies 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 in only a single country.

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 U.S. 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. However, this approach is unsuitable for firm-level data because 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 of 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]

2. It 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, whereas it affects TFP only when technical change is embodied.

3. The 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 is 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.)

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

5. 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).

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 is 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, to 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 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 higher than 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 a 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 that translates directly into productivity growth.

9.2 Theoretical Model

As technical change occurs, new assets acquired often embody efficiency improvements. Take computers as perhaps the most obvious example. Controlling for depreciation and inflation, a computer purchased in 2000 is much different from one purchased in 1990. The reason is that the newer one incorporates the technological improvements that make it more efficient per dollar of investment. Technical change that is not incorporated into specific assets is *disembodied.* An example of this type of technical change is Frederick Winslow Taylor's time and motion studies, which improved how factors of production interact, rather than the inputs themselves.

In mathematical terms, when technical change is disembodied, the capital stock, K_t, is equal to the weighted sum of undepreciated capital from each vintage:[6]

$$(1) \qquad K_t = I_t + (I - \delta)I_{t-1} + \cdots + (1 - \delta)^t I_0,$$

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:

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

where ϕ_t is the level of frontier technology in year t. The growth rate of ϕ is the growth 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.

The capital stock measured in efficiency units is equal to

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

The difference between K_t and I_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:

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

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^I denote the corresponding prices of investment and capital in efficiency units, I can use the accounting identities, $P_t^I I_t = P_t^H H_t$ and $P_t^K K_t = P_t^I J_t$, to express ϕ_t and Ψ_t in terms of prices:

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

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]

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

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

8. It 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.

Specifically, the MNC uses a vector of quasi-fixed factors of production consisting of the parent and affiliates' beginning-of-period quality-adjusted capital, $J_t = (J_{jt})_{j=1}^{n}$, where j indexes the n locations of capital. The variable factors of production are labor, $L_t = (L_{jt})_{j=1}^{n}$ and materials, M_t. The firm produces gross output, Y, using a quasi-concave production function

$$(6) \qquad Y_t = F(J_t, L_t, M_t, t \mid \alpha),$$

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 because 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:

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

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:

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

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

$$(9) \qquad \alpha_{J_d} = \alpha_{K_d} = S_{K_d} = \frac{P_{dt}^{J} J_{dt}}{V_t} = \frac{P_{dt}^{K} K_{dt}}{V_t};$$

$$\alpha_{J_f} = \alpha_{Kf} = S_{K_f} = \frac{P_{ft}^{J} J_{ft}}{V_t} = \frac{P_{ft}^{K} K_{ft}}{V_t},$$

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 data sets 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:

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

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, $\widehat{\mathrm{TFP}}_t$:

$$(11) \qquad \hat{Y}_t = \alpha_{L_d}\hat{L}_{dt} + \alpha_{L_f}\hat{L}_{ft} + \alpha_{K_d}\hat{K}_{dt} + \alpha_{K_f}\hat{K}_{ft} + \alpha_M\hat{M}_t + \widehat{\mathrm{TFP}}_t.$$

In the empirical productivity literature, $\widehat{\mathrm{TFP}}_t$ 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:

$$(12) \qquad \widehat{\mathrm{TFP}}_t = \alpha_{K_d}\Psi_{dt} + \alpha_{K_f}\Psi_{ft} + \lambda_t.$$

Although the growth rate of the average level of productivity, ψ_{jt}, is unobservable, it does depend on observable variables. 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):

$$(13) \qquad \Psi_{jt} = \frac{\Phi_{jt} - \Psi_{j,t-1}}{\Psi_{j,t-1}}\frac{I_{jt}}{K_{j,t-1}} = \varepsilon_{jt}\frac{I_{jt}}{K_{j,t-1}}.$$

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

$$(14) \qquad \widehat{EP}_t = \alpha_{K_d}\Psi_{dt} + \alpha_{K_f}\Psi_{ft} = \alpha_{K_d}\varepsilon_{dt}\frac{I_{dt}}{K_{d,t-1}} + \alpha_{K_f}\varepsilon_{ft}\frac{I_{ft}}{K_{f,t-1}}.$$

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):

$$\text{(15)} \quad \hat{Y}_t = \alpha_{L_d}\hat{L}_{dt} + \alpha_{L_f}\hat{L}_{ft} + \alpha_{K_d}(1 + \varepsilon_{dt})\hat{K}_{dt} + \alpha_{K_f}(1 + \varepsilon_{ft})\hat{K}_{ft} + \alpha_M\hat{M}_t + \alpha_{K_d}\varepsilon_{dt}\delta + \alpha_{K_f}\varepsilon_{ft}\delta + \lambda_t .$$

When capital is measured in unadjusted units the correct output elasticity for growth accounting must 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 next, 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:

$$\text{(16)} \quad q_{jt} = \frac{C_{I_{jt}} + P^I_{jt}}{P^I_{jt}},$$

where $C_{I_{jt}}$ is the marginal adjustment cost for investment in location j.

Consistent with studies in the investment literature, I assume that marginal adjustment costs are linear, $C_{I_{jt}} = \beta_j(I_{jt}/K_{j,t-1}) + v_t$, 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 (1993a) 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 as

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

where β_0 is introduced as an intercept. Although the focus of this paper is not on investment behavior, I estimate the adjustment cost 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, for example, changes in capital income tax policy—will translate into small increases in productivity, regardless of the magnitude of the elasticity of embodiment.

It is important to notice that the size of the adjustment costs are unrestricted in this specification. One might suspect that foreign affiliates' adjustment costs would be lower because their operations are likely to be younger than the parents'; but a sensible case can be made for why adjustment costs may be higher. For example, if adjustment costs for installing capital depend primarily on the flexibility of the labor force, one might expect that it would be more disruptive to the production process to install a machine in a factory in Paris, France, than to install the identical one in Paris, Texas. In some cases, the distinction between domestic and foreign is quite artificial, but this does not pose a conceptual challenge to the approach. Consider the auto industry, in which many assembly plants are similar in the United States and Canada. If U.S. MNCs are, on average, like those in the auto industry, one would expect parent and affiliate adjustment costs to be similar. To the extent that the parent or subsidiary changes its adjustment cost technology, say, by building a new factory in Ontario or Ohio, this will be reflected in the estimates.

In summary, it is tricky to find the true contribution of capital to output growth when the quality of capital goods is unobserved, as it is in most data sets. In order to find the actual contribution, an indirect approach must be used. The key to this indirect approach is inferring the firm's elasticity of embodiment, which defines the bang-for-the-buck from investing in the best available technology. The idea captured by this elasticity is that the contribution to growth of a new computer is higher for a firm using vintage 1950s adding machines than for a firm using one-year-old computers. Then the true contribution of capital to output growth can be found by marking up its observed contribution by this elasticity. Finally, the effects of policy changes can be analyzed by linking investment in new, more efficient capital goods to the Q model, which summarizes the net return to investment by incorporating variable such as taxes and interest rates.

9.3 Empirical Methodology

To sort out the contributions of different factors to output growth, I estimate the production technology introduced in the previous section. Then I can separate the contributions of embodied and disembodied technological change, and use this separation as the basis for inferring the elasticity of embodiment.

An 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:

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

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 of 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. However, the bias will also occur for quasi-fixed inputs because demand for them depends on expected future technology so that those in place are also correlated with u_t. In the results, the estimates using ordinary least squares (OLS) are compared to those from the semiparametric procedure introduced by Olley and Pakes (1996) that corrects for the bias (see Cummins 1999 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

$$(19)\qquad \text{TFP}_{it} = Y_{it} / \exp(\alpha_{L_{dt}} l_{idt} + \alpha_{L_{ft}} l_{ift} + \alpha_{K_d} k_{idt} + \alpha_{K_f} k_{ift} + \alpha_M m_{it}) = \frac{Y_{it}}{Z_{it}}.$$

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

$$(20)\qquad \text{TFP}_t = \sum_{i=1}^{N} \text{TFP}_{it} s_{it} \quad \text{where } s_{it} = \frac{Y_{it}}{\sum_{i=1}^{N} Y_{it}},$$

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

$$\text{TFP}_t = \overline{\text{TFP}_t} + \sum_{i=1}^{N}(s_{it} - \bar{s}_t)(\text{TFP}_{it} - \overline{\text{TFP}_t}). \tag{21}$$

The larger 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 from 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:

$$EP_{it} = \text{TFP}_{it} - \exp\left(\sum_{t=1}^{T}\alpha_t D_t\right). \tag{22}$$

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

9.4 Data

The production function is estimated using a firm-level panel data set 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 U.S. parent firms are from Standard and Poors Compustat Service 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 3 seven-year panels to obtain a data set 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.

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

Consider how to estimate the parameters of the Cobb-Douglas production function when, for example, 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 1999), but the bias is unlikely materially to 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 an MNC reports operations for more than one country I aggregate them and denote the affiliate's country as "multiple." These six countries receive the majority of American MNCs' FDI.

In the geographic segment file, affiliates' data are reported in nominal U.S. 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 U.S. dollars in each year using the current exchange rate and then divides by the U.S. price deflator to form the real series. Because the parent's and affiliate's data are already reported in U.S. dollars in the geographic segment file, I assume that firms accurately translate host-country currencies into U.S. 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 U.S. 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 9.1. The number of MNCs in the sample increases from twenty-eight firms in 1981 to ninety-one firms in 1995. The total number of observations is 1,012. The sample variables are MNCs' 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 means, medians, and standard deviations of the variables. The sample statistics indicate 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

10. Mexico and Brazil are also reported but are excluded.

Table 9.1 **Means, Medians, and Standard Deviations of Selected Sample Variables**

Year	*N*	Gross Output	Parent Employees	Affiliate Employees	Parent Capital	Affiliate Capital	Materials
1981	28	441.1	2,334.4	530.1	304.2	39.0	330.8
		(82.3)	(661.0)	(206.0)	(43.8)	(10.8)	(30.7)
		[1,475.6]	[7,013.2]	[1,430.1]	[758.1]	[97.0]	[1,316.9]
1982	28	338.1	2,153.3	465.2	307.6	29.1	234.8
		(67.8)	(575.5)	(162.5)	(45.2)	(10.9)	(27.6)
		[1,027.4]	[6,257.6]	[1,276.1]	[748.9]	[58.4]	[876.4]
1983	34	298.9	2,179.1	474.5	287.1	27.5	203.2
		(45.1)	(306.0)	(162.5)	(31.1)	(7.8)	(19.7)
		[1,023.0]	[7,566.6]	[1,544.1]	[783.3]	[63.5]	[840.4]
1984	45	373.9	2,538.9	546.0	461.7	63.9	237.9
		(63.8)	(458.0)	(190.0)	(41.3)	(9.4)	(30.9)
		[997.1]	[7,072.4]	[1,308.9]	[1,207.6]	[135.2]	[813.9]
1985	46	458.6	3,974.5	889.6	637.4	69.0	278.3
		(81.9)	(762.0)	(290.5)	(52.6)	(10.8)	(37.1)
		[1,105.9]	[10,233.0]	[1,929.0]	[2,338.9]	[156.6]	[869.6]
1986	55	528.0	4,462.2	1,116.2	385.6	58.4	350.0
		(88.7)	(800.0)	(255.0)	(69.4)	(10.7)	(46.6)
		[1,248.3]	[11,082.0]	[2,672.3]	[791.4]	[122.7]	[957.9]
1987	68	492.5	3,369.6	818.8	394.2	77.9	337.5
		(73.8)	(624.5)	(208.5)	(38.9)	(11.2)	(41.0)
		[1,280.5]	[9,429.0]	[2,022.3]	[840.5]	[199.7]	[1,015.7]
1988	79	641.4	4,565.7	1,090.7	415.3	88.1	448.4
		(67.9)	(440.0)	(205.0)	(39.7)	(9.9)	(37.4)
		[1,890.8]	[13,583.0]	[3,100.1]	[989.2]	[227.5]	[1,528.6]
1989	77	662.9	4,734.5	1,210.3	374.1	97.5	460.6
		(77.3)	(434.0)	(200.0)	(45.9)	(10.5)	(46.3)
		[1,967.1]	[13,840.0]	[3,439.8]	[740.9]	[247.3]	[1,575.1]
1990	88	630.9	4,122.1	1,116.3	638.1	160.1	425.8
		(64.1)	(463.0)	(213.0)	(46.0)	(13.1)	(36.0)
		[1,862.1]	[13,596.0]	[3,331.9]	[2,499.2]	[571.9]	[1,451.5]
1991	90	654.6	3,611.2	1,334.5	815.8	171.8	453.2
		(73.9)	(460.5)	(199.0)	(46.2)	(12.0)	(39.4)
		[1,830.1]	[11,295.0]	[4,608.1]	[2,743.0]	[570.7]	[1,446.2]
1992	90	630.4	4,161.7	664.8	883.3	158.9	439.3
		(92.4)	(479.5)	(176.0)	(64.9)	(13.0)	(49.3)
		[1,721.0]	[14,211.0]	[1,187.8]	[2,971.5]	[507.0]	[1,381.8]
1993	90	736.5	3,857.9	1,039.5	956.9	169.7	535.8
		(119.9)	(684.0)	(223.0)	(91.2)	(16.3)	(66.0)
		[1,959.0]	[12,527.0]	[2,922.5]	[3,311.0]	[537.6]	[1,634.9]
1994	103	602.4	3,047.2	821.9	883.5	137.0	443.6
		(95.4)	(492.0)	(167.0)	(83.0)	(12.0)	(45.7)
		[1,819.5]	[11,438.0]	[2,679.3]	[3,273.2]	[492.8]	[1,537.8]
1995	91	696.2	3,340.9	918.4	938.6	154.4	520.5
		(92.22)	(492.0)	(173.0)	(96.6)	(16.4)	(50.3)
		[1,976.5]	[12,234.0]	[2,867.7]	[3,266.5]	[526.9]	[1,669.7]
Total	1,012	589.9	3,679.9	934.7	650.4	117.7	413.5
		(78.8)	(532.0)	(200.0)	(58.3)	(11.9)	(40.2)
		[1,692.2]	[11,745.0]	[2,813.8]	[2,363.7]	[413.2]	[1,378.5]

Note: The data set is an unbalanced panel of U.S. MNCs. The total number of MNCs in the sample in each year is reported in column (2). For each MNC there are data on capital and labor for the parent and its affiliates (which are aggregated across countries into a single affiliate). Data on gross output and materials are for the MNC as a whole. Variables are in \$ millions (1987), except "Employees" which are in units. Medians of the variables are in parentheses below the means. Standard deviation of the variables are in square brackets below the means.

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. The number of firms declines in 1995 because the U.S. Securities and Exchange Commission (SEC), in Financial Reporting Release no. 44, eliminated the requirement that firms report detailed data about their property, plant, and equipment (see http://www.sec.gov/rules/final/dissuer.txt).

9.5 Empirical Results

I present the empirical results in three parts. The first subsection contains the estimates of the production function, which form the basis of the decomposition of the sources of growth in the second. In the last subsection I highlight the role of tax policy in the growth of MNCs by showing how it can affect productivity directly through investment by changing the after-tax price of capital.

9.5.1 Production Function Estimation

Table 9.2 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 1 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; comments by Baily 1986; Grubb 1986). I concentrate, then, on the results in columns (3) and (4).

Comparing the estimates from OLS in column (3) to the ones from the

11. There were sixteen 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 (1) and (2) is sixteen less than in (3) and (4).

Table 9.2 Cobb-Douglas Production Function Parameter Estimates

	Value Added		Gross Output	
Parameter	OLS (1)	Semiparametric (2)	OLS (3)	Semiparametric (4)
L_d	0.602	0.611	0.288	0.281
	(0.031)	(0.033)	(0.018)	(0.019)
L_f	0.112	0.102	0.065	0.074
	(0.028)	(0.029)	(0.016)	(0.017)
K_d	0.259	0.207	0.171	0.131
	(0.018)	(0.023)	(0.011)	(0.012)
K_f	0.055	0.041	0.058	0.085
	(0.013)	(0.024)	(0.008)	(0.013)
M	—	—	0.427	0.423
			(0.010)	(0.011)
N	996	996	1,012	1,012

Note: The dependent variable in columns (1) and (2) is value added. The dependent variable in columns (3) and (4) is gross output. Standard errors on parameter estimates are in parentheses. The semiparametric estimator is described in the text and in detail in Cummins (1999).

semiparametric estimator in column (4) 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 parents' capital and smaller contributions from affiliates' factors. The implied returns to scale in column (3) are 1.01, and 0.99 in column (4). The estimated parameters then are approximately equal to their factor shares when perfect competition is assumed. The estimates of the parents' employment share and materials are virtually identical using either estimator. This is somewhat surprising, because 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 (4), the total share of parents' inputs is about 0.41 and the total share of affiliates' inputs is about 0.16. Notably, the ratio of the parents' output elasticity of capital to its output elasticity of labor is about 0.45, whereas the affiliates' ratio is about 1.1. If the ratio of the rental price of capital and the wage are the same in the United States and abroad, the ratios of the output elasticities are proportional to the capital-labor ratio, implying that the affiliates are much more capital intensive.

9.5.2 Sources of MNC Growth

Table 9.3 contains the aggregate indexes of factor inputs. Each index is calculated as the annual average of the firm-level factor inputs using gross

Table 9.3 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 (%)				
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

Note: 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 (4) of table 9.2 as shares.

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, because it is unweighted by its share in output.

To calculate average annual share-weighted growth rates, the parameter estimates in column (4) of table 9.2 are used as shares. In the bottom panel of the table the average annual growth rates are presented for the whole period and 3 five-year subperiods. Over the entire period the share-weighted growth rates of capital are the largest contributors to growth. Although 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 subperiods, although the contributions of capital are smaller recently.

In table 9.4, 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 (4) of table 9.2. The weighted index in column (1) uses firm-level gross output shares as weights (see equation [20]). The percent of embodied and disembodied technical change in columns (2) and (3) 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 (4). The percent of embodied and disembodied technical change in unweighted TFP are in columns (5) and (6). Finally, the difference between the weighted and unweighted indexes is $\mathrm{Cov}(\mathrm{TFP}_{it}, Y_{it})$, the sample covariance between TFP and gross output.

Both weighted and unweighted TFP have declined over the sample period. Thus $\widehat{\mathrm{TFP}}_t$ 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, a number of studies have used microdata and have found 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 3 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.

Table 9.4 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

Note: The aggregate productivity index is calculated as the annual average of the firm-level productivity estimates from the semiparametric specification in column (4) of table 9.2. "Weighted TFP Index" uses firm-level gross output shares as weights. "Percent Disembodied" technical change is the share of productivity attributable to year dummy variables in TFP. "Percent 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.

Figures 9.1 and 9.2 illustrate this boom. The first plots the two indexes from table 9.4 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 the North American Free Trade Agreement (NAFTA), suggesting that productivity may be associated with freer trade. I investigate this possibility in figures 9.3 and 9.4. Figure 9.3 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 9.4 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 because 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 9.6 using regression analysis.)

Table 9.5 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 9.4, 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 column (1) is calculated as the affiliate country average of the firm-level productivity estimates from the semiparametric specification in column (4) of table 9.2. 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, although it accounts for about 21 percent of productivity in Japan. The unweighted TFP index is in column (4). Relative to Canadian affiliates, no other countries' affiliates have greater unweighted productivity. Finally, in column (7), 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

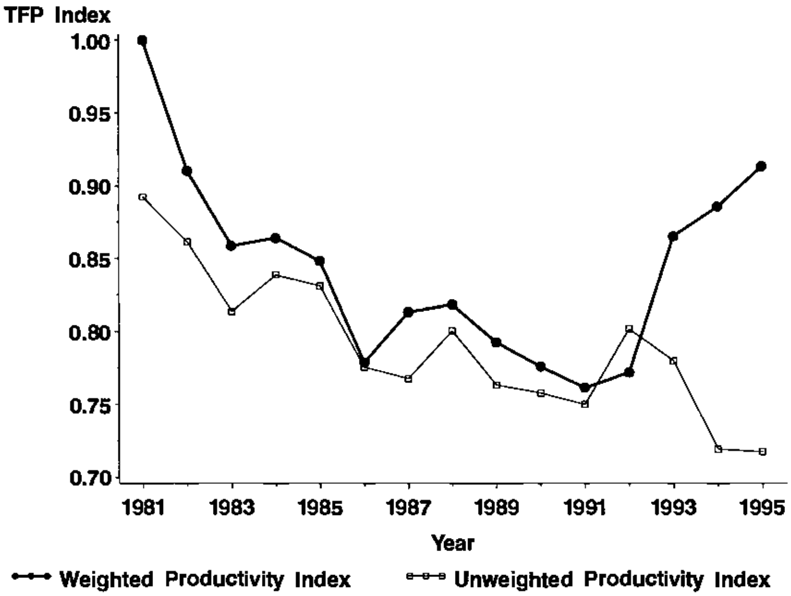

Fig. 9.1 Aggregate TFP indexes

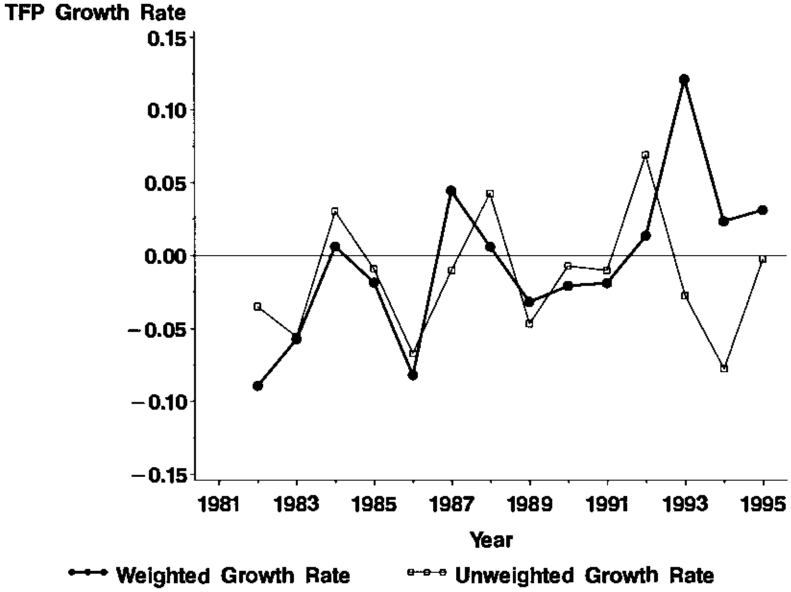

Fig. 9.2 Growth rates of weighted and unweighted TFP

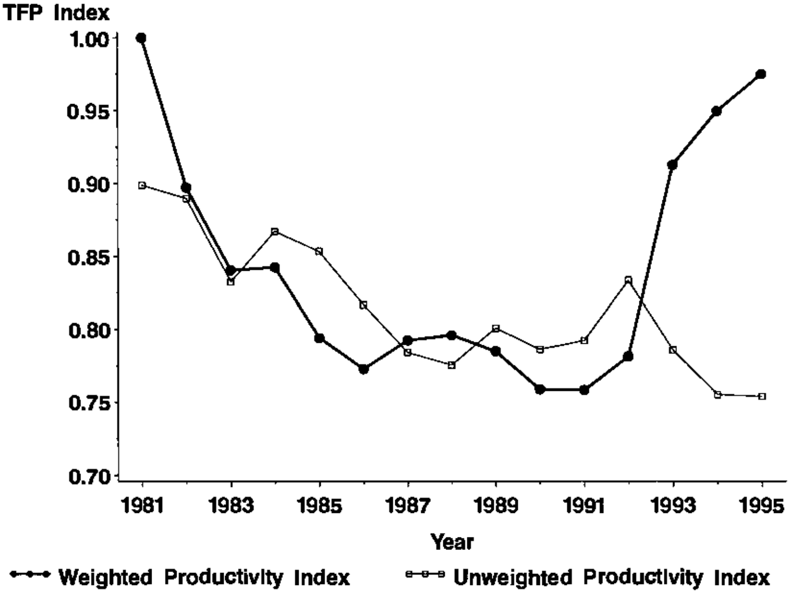

Fig. 9.3 Aggregate TFP indexes: Canadian affiliates

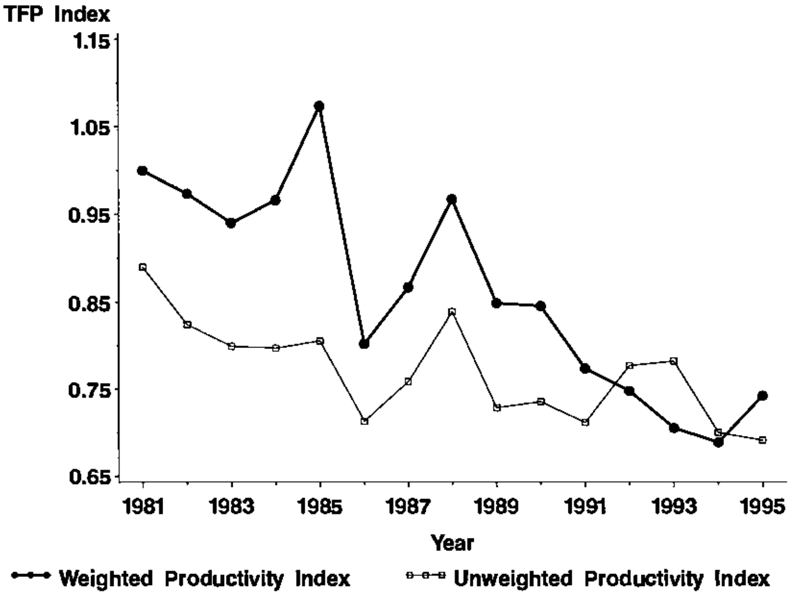

Fig. 9.4 Aggregate TFP indexes: non-Canadian affiliates

Table 9.5 **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

Note: The aggregate productivity index is calculated as the affiliate country average of the firm-level productivity estimates from the semiparametric specification in column (4) of table 9.2. Canada is the base of the index. "Weighted TFP Index" uses firm-level gross output shares as weights. "Percent Disembodied" technical change is the share of productivity attributable to year dummy variables in TFP. "Percent 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.

from less productive to more productive MNCs. The exceptions are Australia and the United Kingdom, where the covariance is negative but close to zero. In these countries, changes in average productivity, not a reallocation of output from less productive to more productive firms, drives productivity growth.

9.5.3 Linking Taxation, Investment, and Productivity

The estimates in table 9.6 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 because 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. Because 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 used as the 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 included only as additional regressors.[12]

12. Cummins 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. Because 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.

Table 9.6 **Investment and Embodied Technical Change: Estimates of Adjustment Cost Parameters and the Elasticities of Embodiment**

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

Note: The investment relationship estimated is defined by equation (17). The embodiment relationship estimated is defined by equation 14. The dependent variable in column (1) is tax-adjusted Q_{it}. The dependent variable in column (2) is real Q_{it}. The dependent variable in column (3) 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.

It is important to highlight the role of the sources of variation in the data. Variation in the after-tax price of capital is *not* essential for estimating equation (17), unlike in the usual specification in which tax-adjusted Q is the regressor. For example, if Q is subject to additive measurement error as a result of removing the tax adjustment, then the estimates of equation (17) are still consistent. Taxes are nonetheless included in the model so that the elasticity of investment with respect to its after-tax price can be calculated and used for policy experiments.

In the first column the dependent variable is tax-adjusted average Q (for details on the construction of this variable, see Cummins, Hassett, and Hubbard 1994). The parameter estimates are statistically significant and imply marginal adjustment costs of investment that are small compared to those in many studies (see, e.g., Chirinko 1993b). The estimates for the parents' adjustment costs are similar to those obtained by Cummins et al. (1994) for U.S. 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 (1999) and Cummins and Hubbard (1995). The number of observations drops because some of the data necessary to calculate tax-adjusted Q are missing. In column (2) the dependent variable is real Q constructed by Cummins, Hassett, and Oliner (1999) from securities analysts' earnings expectations. This measure has theoretical and empirical appeal because 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 column (3), 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 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 10 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 higher than the average level in parents, but indistinguishably different from the average in affiliates. While there is no data on the average age of the parents' and affiliates' capital stock, it is likely that the parents' stock is older. Hence, despite the numerous assumptions underlying this approach, the results are at least sensible.

The sizes 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, whereas

13. It would be preferable to relax the assumption that the disturbance is orthogonal to the regressors and use an instrumental variable estimator such as generalized method of moments (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.

14. All 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, because 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.

15. The 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 because there are only 14 observations.

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 9.3 increases its contribution to growth from 1.49 to 2.48 percent. In studies that ignore quality adjustment, this additional contribution to growth is spuriously attributed to TFP, not to 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 parents' and affiliates' 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.

9.6 Conclusion

The growth accounting for U.S. MNCs indicates that 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 recovered in the 1990s. This general trend masks two very different experiences. MNCs with Canadian affiliates have had a productivity boom since 1992, whereas MNCs with affiliates elsewhere have continued their slides. There are wide cross-sectional differences among MNCs depending on where their affiliates operate. The MNCs with affiliates in the United Kingdom 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. Most of 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. Other studies have found the opposite. For example, Bahk and Gort (1993) show that quality improvements are associated with statistically and economically significant growth effects. Specifically, they find that a one-year change in the average age of the capital stock is associated with a 2.5–3.5 percent change in output. In this study, improvements in the quality of capital are important as well. The already large contribution of parent capital to growth are marked up significantly because of embodied technical change. Because the parents' 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 suggests the possibility that tax incentives for capital increase productivity and growth.

Appendix

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 affiliates' 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 Wykoff (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 data set to construct the parent's and affiliates' labor input from total employees. The U.S. 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 U.S. Department of Commerce 1995). Using these data, I construct the percentage 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 correspond exactly to the firm-level Standard Industry Classification (SIC) 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 because the survey from which the weights are constructed includes the MNCs in our firm-level data.[18]

16. Major 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.

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

18. I checked the accuracy of this method by comparing the employee numbers to those from the companies' annual reports. I picked a random sample of twenty MNCs from the sample and found that in most cases our method gave numbers within 10 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 average sectoral 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 2,040-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 et al. (1999).

Home-and host-country tax variables (federal and subfederal corporate income tax rates, investment tax credits, depreciation allowances, and withholding tax rates on repatriated dividends) are updated and expanded from Cummins et al. (1995).[19] The price of capital and output goods are, respectively, the property, plant, and equipment deflator (PPE) and the GDP deflator of the United States. All capital and investment variables are deflated by the U.S. PPE deflator and output is deflated by the U.S. GDP deflator.

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Comment Samuel S. Kortum

What is the contribution of different factors of production and technological change to the growth of MNCs since the 1980s? Would changes in the taxation of these corporations substantially alter their growth? Cummins approaches the first question with new data on U.S.-based multinationals that allow him to identify the impact of parent and affiliate capital and labor. For the second question he adopts a model in which technological change is embodied in investment goods, so that a jump in investment raises productivity as well as the capital stock. He concludes that capital—with a surprisingly large contribution of affiliate capital—played the major role in the growth of MNCs. Technological change contributed little. On the second question, Cummins suggests that the productivity gains from an investment-promoting tax policy could be substantial.

I argue that these conclusions should be tempered. With respect to the first question, I raise some questions concerning the specification of the MNC's production function. For the second, I show that the productivity impact of higher investment is fleeting. Nevertheless, I applaud Cummins on his research agenda concerning MNCs and on his empirical strategy in particular. Given their growing importance in the world economy, it is crucial that economists get a better handle on the workings of the MNC. By linking data on parents and their affiliates, Cummins can do just that. Many others will likely follow his lead.

I begin by discussing the MNC's production function. In the paper, the output of the entire MNC is aggregated, whereas the capital and labor of both affiliate and parent enter as four distinct inputs into a Cobb-Douglas

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production function. A more natural assumption is that the Cobb-Douglas production function applies separately to the output of the parent and the output of its affiliates. If so, and if affiliates are growing faster than their parents, then the paper's estimates of disembodied technological change are biased down in the earlier years of the sample and biased up in the later years. This argument could explain the finding that disembodied technological change is negative in the first half of the sample, then recovers in the latter half.

I then probe the model of capital embodied technological change that the paper adopts. Although introducing embodied technology augments capital's contribution to growth in an accounting sense, it turns out to make little difference to the output effect of a policy-induced increase in investment. The impact on productivity of a jump in investment, driven by changes in the age distribution of capital, is short lived and eventually reverses itself. I make this point analytically and with a simulation based on parameter values from the paper.

The Multinational's Production Function

Because production by a domestic parent Y_d and its foreign affiliate Y_f take place in separate locations, it makes sense to explain each in terms of its own production function. Ignoring materials inputs, we have $Y_d = F_d(K_d, L_d, A_d)$ and $Y_f = F_f(K_f, L_f, A_f)$. Of course there may be links between production of the parent and its affiliate. The most plausible link, and a possible reason for the MNC to exist in the first place, is that the affiliate inherits its technology A_f in part from the knowledge A_d of its parent. An exploration of this link, however, is for another paper.

The present paper is concerned with decomposing the growth of the output of the entire multinational $Y = Y_d + Y_f$. It begins with a production function for Y, which in the empirical work is a Cobb-Douglas function of K_d, K_f, L_d, and L_f. In growth rates (denoted by hats)

$$\hat{Y} = \hat{A} + \alpha_{K_d}\hat{K}_d + \alpha_{K_f}\hat{K}_f + \alpha_{L_d}\hat{L}_d + \alpha_{L_f}\hat{L}_f, \tag{1}$$

a simplified version of equation (10) in Cummins's paper.

Suppose we adopt the Cobb-Douglas functional form (with parameters β) but maintain the principle that a separate production function governs the output of the parent and the affiliate. The resulting equation for output growth is

$$\begin{aligned}\hat{Y} = {} & s_d\hat{A}_d + (1 - s_d)\hat{A}_f + s_d\beta_{K_d}\hat{K}_d + (1 - s_d)\beta_{K_f}\hat{K}_f \\ & + s_d\beta_{L_d}\hat{L}_d + (1 - s_d)\beta_{L_f}\hat{L}_f,\end{aligned} \tag{2}$$

where $s_d = Y_d/Y$ is the parent's share of the multinational. In equation (2), the output elasticity of affiliate capital is automatically larger in an MNC where affiliates play a larger role. This implication is intuitive and its absence from equation (1) raises questions about that specification. Doubling the capital stock of an affiliate, if it is tiny relative to the parent, is unlikely to produce a large percentage increase in the MNC's total output. A similar argument applies over time.

With globalization of production, affiliates will become a larger share of multinational output and s_d will fall over time. If equation (2) is correct, then the estimates of equation (1) will be time averages of the corresponding coefficients in equation (2). The true output elasticities of K_f and L_f will be less than the estimated elasticities in the early years and greater toward the end of the sample (the opposite will be the case with the output elasticities of K_d and L_d). However, with affiliates growing faster than parents, presumably $\hat{K}_f > \hat{K}_d$ and $\hat{L}_f > \hat{L}_d$ (table 9.3 of the paper verifies these inequalities). It follows that the rate of disembodied technological change inferred from the estimates will be less than the true rate $s_d\hat{A}_d + (1 - s_d)\hat{A}_f$ early in the sample and greater than the true rate toward the end.

Technology Embodied in Capital

With personal computers everywhere, we are accustomed to technological change arriving in new equipment. The model of capital embodied technology captures that feature of reality in a simple way. Physical investment I is the rate at which new machines are brought into production. Adding up machines (allowing for a geometric depreciation rate δ), the capital stock K satisfies $\dot{K} = I - \delta K$. If the capability of new machinery is improving at rate $a > 0$, then investment in efficiency units is $H_t = e^{at}I_t$. The effective capital stock J (which is what should enter the production function) satisfies $\dot{J} = H - \delta J$. Assuming a Cobb-Douglas production function with a capital elasticity α_K, the contribution of capital to output growth is $\alpha_K\hat{J}$.

The elasticity of embodiment $\varepsilon = [(H/J) - (I/K)]/(I/K)$ summarizes what we need to know about the age of machinery. Multiplying the elasticity by 100, it represents the percentage change in the effective capital stock brought about by replacing all existing machines with new ones (holding fixed K). The contribution of capital to output growth can be expressed, like the paper's equation (15), as $\alpha_K\hat{J} = \alpha_K(1 + \varepsilon)\hat{K} + \alpha_K\varepsilon\delta$. Because not all machinery is brand new, $\varepsilon > 0$. Hence, according to the accounting equation, capital contributes more to growth because it embodies new technology (i.e., the output elasticity of K exceeds α_K), but this interpretation may be misleading.

When we look at what tax policy might achieve, the role of capital embodied technology turns out to be modest and transitory. The contribution of capital to output growth consists of three parts: (1) the physical capital effect $\alpha_K\hat{K}$, (2) the technological change effect $\alpha_K a$, and (3) the capital age effect $\alpha_K\hat{X}$, where $X = (J/K)(I/H) = 1/(1 + \varepsilon)$. The physical capital effect

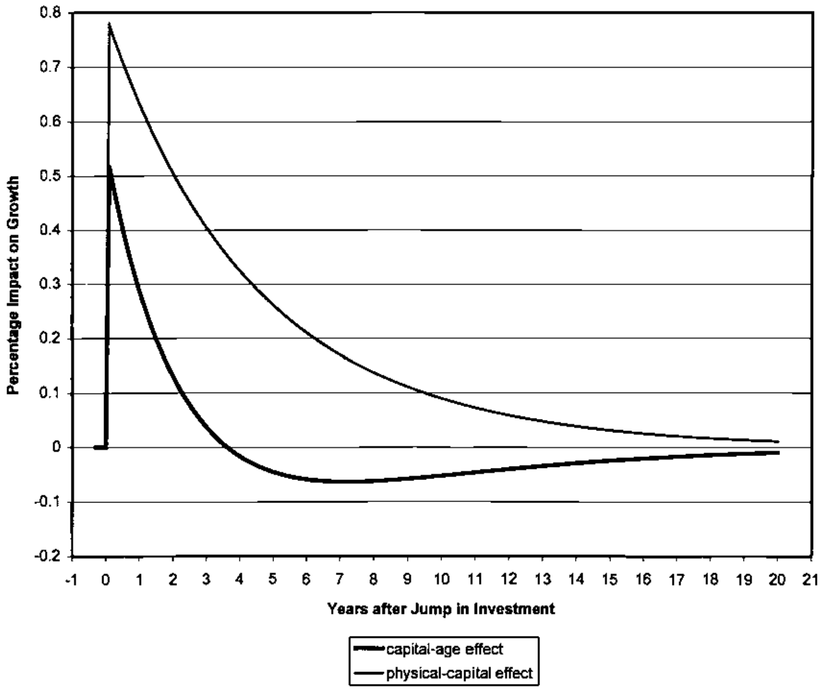

Fig. 9C.1 Effects on growth of a permanent 10 percent jump in investment

is the same as in the standard model and the technological change effect is exogenous. Any new action must come through the capital age effect. Surprisingly, however, tax policies that permanently raise the level of investment have no long-run effect on the age distribution of capital. Not only is there no permanent growth effect through the age channel, there is not even a permanent level effect. The only long-run impact of tax policy is through the traditional channel of a permanently higher physical capital stock.

To see this, assume that investment grows at a constant rate g (a policy change can be thought of as a discontinuous jump in the path of investment). Eventually K will also grow at approximately rate g. In a steady-state situation with stocks and flows growing at the same rate, $I/K = g + \delta$ and $H/J = g + \delta + a$. It follows that $\varepsilon = a/(g + \delta)$. The *level* of investment, which could perhaps be raised permanently by policy, does not matter in the long run for the age distribution of capital. In the short run, however, a jump in the level of investment begins to reduce the average age of capital. We now turn to the dynamics whereby the age of capital first falls and then rises again to its original level.

We simulate the path of the capital age effect $\alpha_K\hat{X} = \alpha_K[(H/J) - (I/K) -$

a] following a 10 percent jump in the level of investment. For the simulation, (1) we initialized H/J and I/K at their steady-state values (prior to the jump in investment); (2) we set the depreciation rate at $\delta = 0.1$; (3) we set investment growth at $g = 0.11$ (the growth of parent capital from table 9.3); (4) we set embodied technological change at $a = 0.14$, so that the steady-state elasticity of embodiment is 2/3 (as in table 9.6); and (5) we set $\alpha_K = 0.37$ based on the estimates in the last column of table 9.2 (dividing the sum of the capital elasticities by $1 - \alpha_M$). Note that our parameter choices, although perhaps extreme, are designed to give the capital age effect its best shot.

Figure 9C.1 shows what happens. Initially, the capital age effect (the fat line) contributes half a percentage point to growth, exactly what is predicted by equation (14) in the paper ($10\alpha_K \varepsilon I/K = 10\alpha_K a = 0.5$). However, the capital age effect has turned negative by four years out and stays negative thereafter while slowly diminishing toward zero. For comparison, we also plot (as a thin line) the traditional physical capital effect (less its steady-state value of $\alpha_K g$). Although the capital age effect is more than half as large as the physical capital effect in the first year, it falls much more rapidly.

The bottom line is that one should not expect a big or long lasting contribution from the capital age effect. Consequently, because the capital age effect is the mechanism by which tax policy could raise productivity, one should not hope for big productivity effects. The growth impact of rising physical capital dwarfs the impact of shifts in the age distribution of capital.