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Productivity Growth in the Motor Vehicle Industry, 1970–1984: A Comparison of Canada, Japan, and the United States

Melvyn Fuss and Leonard Waverman

3.1 Introduction

The motor vehicle industry is perhaps the prime example of the Japanese competitive threat to U.S. manufacturing. Aided by the oil price shocks of the 1970s, Japanese imports developed into an important segment of the North American market for vehicles and have come to enjoy a reputation for low cost and high quality compared with domestic products. In response to these Japanese inroads, both Canada and the United States in 1981 placed quotas on Japanese imports (the Voluntary Export Restraints Agreements). The G.M.-Toyota joint venture in automobile stamping and assembly in Fremont, California was approved by the U.S. government in 1985, despite antitrust concerns, in the hope that this would accelerate the transfer of Japanese production methods to North America.

Changing circumstances in the international environment for production and trade in motor vehicles can be thoughtfully analyzed only if knowledge is available about the trends, over time, of cost and productivity differentials and the sources of these differences. It is important to determine whether different growth rates of cost are due to variations among nations in factor price growth rates or in changes in technological conditions such as economies of scale, capacity utilization, and the rate of technical progress.

In this study we utilize an econometric cost function and a decomposition

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analysis of that function to measure the growth in average cost and productivity in motor vehicle production in Canada, the United States, and Japan over the period 1970–84 and to determine the sources of growth. Unlike previous studies of this industry, we are particularly careful to take into account short-run disequilibrium effects. The major source of disequilibrium in the auto industry is the periodic underutilization of capacity. The auto industry is an industry characterized by quasi-fixed factors (capital and overhead labor) and product-specific manufacturing facilities. Swings in consumer tastes among different products can lead to variations in capacity utilization that affect measured cost and total factor productivity growth to a significant extent. The empirical results presented below indicate that, had capacity utilization effects not been accounted for, we would have overestimated long-run total factor productivity (TFP) growth during the 1970–84 period by 22% in the United States and 21% in Canada. This problem is much more severe for the two subperiods we consider: 1970–80 and 1980–84. We control for utilization effects by including a measure of capacity utilization as an argument of the cost function.

The Japanese productivity "miracle" is evident from our results for motor vehicle production. During the period 1970–84 total factor productivity in the Japanese industry grew at an average rate of 3.0% per annum. By way of contrast, the Canadian and U.S. automotive industries experienced average per annum utilization-corrected TFP growth rates of only 0.9% and 1.1% respectively, about one-third of the Japanese rates. The more rapid efficiency gain in Japan is a major reason why long-run average cost, as measured in each country's own currency, grew at only a 2.5% annual rate for Japanese vehicle production, whereas long-run average cost increased at a 7.1% rate in Canada and at a 6.6% rate in the United States.

As noted previously, these empirical results are obtained from an estimated econometric cost function and a decomposition analysis. In section 3.2 we present a nontechnical explanation of cost and efficiency measurement and decomposition. The specific empirical results are presented in sections 3.3 and 3.4. In section 3.5 we conclude the paper's main discussion with some summary remarks. Data are presented in appendix A, and a formal analysis of the underlying theory appears in the technical appendix (app. B).

3.2 The Cost Function Approach to the Analysis of Cost and TFP Growth Rates

We begin by assuming that the motor vehicle production process can be represented indirectly by the cost function

$$C_{it} = G_{it}(w_{it}, Q_{it}, T_{it}), \tag{1}$$

where C_{it} is the total cost of production in country i at time t, w_{it} is a vector of factor prices, Q_{it} is the level of output, and T_{it} is a vector of technological conditions that could be viewed as the "characteristics" of the production process. Examples of characteristics to be used in this study are an index of research and development (R&D) expenditures (a proxy for technical change) and capacity utilization. Since capacity utilization (T_{1it}) is an explanatory variable in the cost function, Q_{it} will be defined as full (normal) capacity output. Actual output will be denoted q_{it}, where $q_{it} = Q_{it} \cdot T_{1it}$. Then Q_{it} is the output produced when the firm is operating at full utilization ($T_{1it} = 1$).

The cost function (1) is the solution to the firm's problem of minimizing the cost of producing output conditional on the exogenous factor prices and the levels of characteristics. Given the assumption of cost-minimizing behavior, the theory of duality between cost and production insures that the cost function is as basic a tool of analysis as the production function and can be used to estimate any desired aspect of the production process, including TFP growth.[1] In this paper we measure TFP growth by the growth in cost efficiency (CE). This CE growth is defined as the reduction in average minimum *real* cost over time; that is, the reduction in average cost that occurs after the effects of intertemporal changes in factor prices have been accounted for. Hence, CE is dual to TFP, since TFP growth measures the improvement in the efficiency of the use of inputs over time. In the technical appendix (app. B) we demonstrate that the rate of TFP growth is equal to the rate of CE growth, so that either concept can be used to measure intertemporal efficiency improvements. The formula that we will use to measure CE growth is the translog (Törnqvist) index of cost efficiency growth between periods 0 and 1 (Denny, Fuss, and May 1981),

$$(2)\quad \log \mathrm{CE}_{i1} - \log \mathrm{CE}_{i0} = -\,[\log(C_{i1}/q_{i1}) - \log(C_{i0}/q_{i0}) \\ - \tfrac{1}{2}\sum_{k=1}^{K}(s_{ki1} + s_{ki0})(\log w_{ki1} - \log w_{ki0})],$$

where s_{ki1} is the cost share of the kth input in country i in period 1. The minus sign in front of the right-hand side of (2) is to convert an efficiency gain that *lowers* average cost into a positive quantity. Following Denny and Fuss (1983), we call (2) a translog index if C_{i1}, C_{i0}, s_{ki1}, s_{ki0} are estimated from an econometric cost function, and a Törnqvist index if they are measured directly from the actual observed data. Equation (2) is derived in the technical appendix, and shown to be closely linked to the assumption that the motor vehicle production process can be represented by a translog cost function in which the zero- and first-order parameters differ across countries, but the second-order parameters are the same for each country.

3.2.1 Cost and Productivity Growth—a Decomposition Analysis

One of the purposes of this paper is to compare average cost and TFP growth rates for Canada, the United States, and Japan over the 1970–84 period. A second purpose is to decompose these growth rates into their sources.

In this section we present a graphical representation of the decomposition analysis. The equations corresponding to the graphs are contained in the technical appendix.

Suppose (C_0, q_0, p_{L0}, p_{K0}, T_{10}, T_{20}) and C_1, q_1, p_{L1}, p_{K1}, T_{11}, T_{21}) represent observed cost, actual output, prices of labor and capital services,[2] the capacity utilization rate, and an index of the state of technology in years 0 and 1, respectively.[3] As a first step, we wish to decompose the increase in average cost ($C_1/q_1 - C_0/q_0$) into its sources. The graphical presentation is greatly simplified by changing the decomposition to one involving cost per unit of capacity output ($C_1/Q_1 - C_0/Q_0$). This decomposition can easily be linked to the decomposition of actual average cost (as is done in the technical appendix) since $(C/q) = (C/T_1 \cdot Q)$. Equation (1) can be transformed into a per unit of capacity (or average) cost function by dividing both sides by Q_{it}:

$$C_{it}/Q_{it} = H_{it}(w_{it}, Q_{it}, T_{it}). \tag{3}$$

Figure 3.1 contains a series of per unit capacity output cost curves, which can be used to represent the decomposition analysis. To simplify notation,

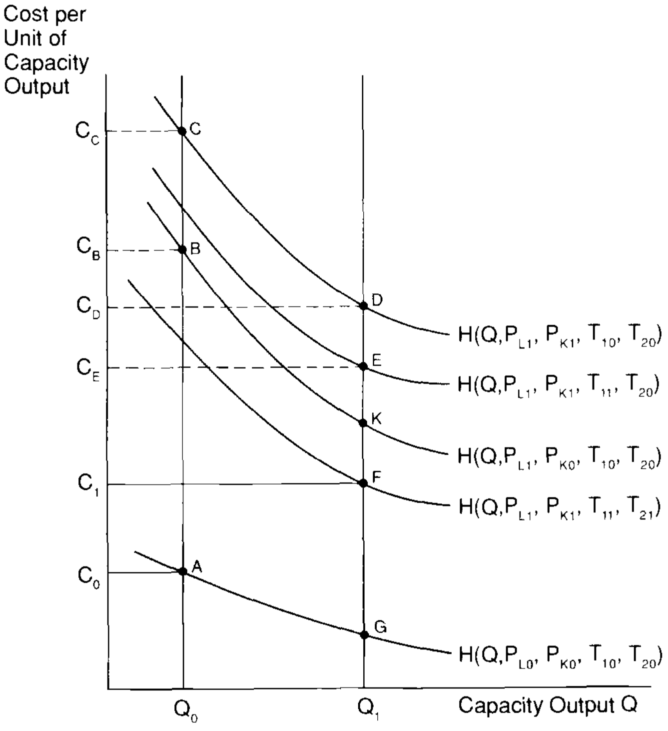

Fig. 3.1 The decomposition of changes in average cost

Table 3.1 **Average Production Cost Increase and Its Sources**

	Source of Increase				
Average Cost Increase (1)	Price of Labor (2)	Price of Capital (3)	Scale Economies (4)	Capacity Utilization (5)	Technical Change (6)
$C_1 - C_0$	$C_B - C_0$	$C_C - C_B$	$C_D - C_C$	$C_E - C_D$	$C_1 - C_E$

from this point on we will denote average cost by C rather than C/Q. All variables are assumed to increase between periods 0 and 1. An increase in the price of labor services from p_{L0} to p_{L1} shifts the average cost curve up and average cost increases from C_0 to C_B, ceteris paribus. Therefore the labor price increase could be said to be the source of $C_B - C_0$ of the average cost increase $C_1 - C_0$. In an analogous way we could decompose the average cost increase into the remainder of its sources as is represented in table 3.1. The movement from A to B to C in figure 3.1 represents the effect of factor price increases, and results in an average cost increase. Increases in capacity output (under increasing returns to scale), capacity utilization, and improvements in the state of technology ($T_{21} > T_{20}$) reduce average cost; hence the negative effects associated with the movement from C to D to E to F.

Recall that once the price effects are removed from the average cost increase, the remainder is the average cost change due to cost efficiency effects (eq. [2]). Therefore the CE change (ΔCE) can be measured in figure 3.1 as the (positive) movement from C to F, or

$$(4) \qquad \begin{aligned} \Delta CE &= -\{C_1 - [C_0 + (C_B - C_0) + (C_C - C_B]\} \\ &= -\{C_1 - C_0 - [(C_B - C_0) + (C_C - C_B)]\}, \end{aligned}$$

which is the graphical representation of equation (2) (with Q_i replacing q_i),[4] in absolute rather than logarithmic differences. The expression − ΔCE is also {column (1) − [column (2) + column (3)]} in table 3.1.

From figure 3.1 it is obvious that ΔCE, the movement from C to F, can also be represented by

$$(5) \qquad \Delta CE = -[(C_D - C_C) + (C_E - C_D) + (C_1 - C_E)].$$

Thus −ΔCE is the sum of columns (4) + (5) + (6) in table 3.1. Cost efficiency (TFP) growth has as its sources: capacity output growth under increasing returns to scale, increased capacity utilization, and improvements in the state of technology (technical progress). Improvements in the state of technology are usually associated with shifts in the cost (or production) function. As the above discussion demonstrates, cost efficiency (or TFP) growth is identical to a shifting of the relevant function only if production is subject to constant returns to scale ($C_D - C_C = 0$) and capacity utilization is constant

Table 3.2 **Total Factor Productivity (TFP) Growth and Its Sources**

	Source of Growth		
TFP Growth (1)	Scale Economies (2)	Capacity Utilization (3)	Technical Change (4)
$-(C_1 - C_C)$	$-(C_D - C_C)$	$-(C_E - C_D)$	$-(C_1 - C_E)$

$(C_E - C_D = 0)$. If these assumptions are not satisfied, TFP growth can be decomposed into its sources as depicted in table 3.2.

The decomposition outlined above is not unique. For example, another possible decomposition of the change in average cost is: A to G (scale economies), G to K (price of labor), K to D (price of capital), D to E (capacity utilization), and E to F (technical change). The choice of decomposition is equivalent to the inevitable necessary choice of weights with which to weight the changes in the variables that are the sources of average cost or TFP growth. Corresponding to each aggregation formula will be a correct weighing procedure. For the translog (Törnqvist) model that underlies our empirical results, the correct weights are the average cost elasticities averaged over time periods 0 and 1. These weights are applied to the logarithms of the relative change in variables—that is, log (p_{L1}/p_{L0})—to decompose the logarithm of relative average cost or relative TFP. Details are presented in the technical appendix.

3.3 Empirical Results: Cost Function Estimation

The analysis of the sources of TFP growth between 1970 and 1984 for the three countries' motor vehicle industries is based on an estimated translog cost function.[5] The cost function was estimated using annual pooled three-digit SIC motor vehicle production data (assembly + parts production) from Canada (1961–84), Japan (1968–84), and the United States (1961–84). The arguments of the cost function are prices of labor, capital, and materials (w_{it}), constant dollar average capacity production of vehicles and parts per plant (Q_{it}), capacity utilization rate (T_{1it}), and an index of the real stock of R&D expenditures (T_{2it}). C_{it} is total cost per plant. A more detailed description of the data is contained in the data appendix.

The translog cost function and the cost share equations (obtained by applying Shephard's lemma to the cost function) were used to form a system of equations, and the parameters of the system were estimated using the Zellner iterative technique to obtain maximum-likelihood estimates. Initial estimation implied the existence of positive serial correlation in the share equations and a violation of concavity at several data points. A first-order autocorrelation specification for share equations was adopted (see Berndt and Savin 1975), and the parameter constraints necessary to insure concavity over the sample were imposed.[6] The exact specification of the cost function and additional details of the estimation procedure are contained in Fuss and Waverman (1990). Also contained in an unpublished appendix to that reference is the list of parameter estimates, their asymptotic standard errors, and the usual diagnostic summary statistics. This appendix is available upon request from the authors.

Instead of attempting to digest the detailed regression results, it is more useful if the reader acquires some idea of the estimated structure of production, since this estimated structure underlies the decomposition results to be presented below. Tables 3.3 and 3.4 present estimates of factor own price elasticities, elasticities of substitution, and other elasticities of interest, calculated assuming full capacity utilization ($T_{1it} = 1$). These results provide a characterization of the long-run equilibrium structure. Table 3.3 demonstrates that all factors are inelastically demanded in the three countries, and all factors are substitutes for one another. From Table 3.4 it can be seen that production in the United States and Japan is subject to slightly increasing returns to scale at the mean data point, but the departure from constant returns is not statistically significant. For Canada, production is subject to statistically significant and economically important increasing returns to scale. Any increase in research and development expenditures appears to have more of a cost-reducing impact in Japan than in the United States. R&D has the least cost-reducing impact in Canada.

The input-capacity output elasticities suggest that the production processes in all three countries are nonhomothetic, with capacity expansion utilizing

Table 3.3 **Factor Own-Price Elasticities and Elasticities of Substitution**

Inputs	Canada	United States	Japan
Factor own-price elasticities:			
Capital	−.06	−.12	−.13
	(.04)	(.03)	(.01)
Materials	−.10	−.14	−.08
	(.03)	(.03)	(.03)
Labor	−.45	−.49	−.36
	(.13)	(.10)	(.17)
Elasticities of substitution (Allen-Uzawa):			
Capital-materials	.03	.05	.16
	(.05)	(.05)	(.01)
Capital-labor	.24	.46	.09
	(.05)	(.03)	(.03)
Labor-materials	.59	.65	.48
	(.18)	(.15)	(.23)

Note: Computed at the mean data point for each country. Approximate standard errors appear in parentheses.

Table 3.4 **Capacity Output Elasticities, Scale Elasticities, and Technical Change Elasticities**

Elasticity	Canada	United States	Japan
Cost–capacity output	.87	.93	.93
	(.04)	(.05)	(.05)
Scale	1.16	1.07	1.07
	(.05)	(.05)	(.06)
Cost–technical change	−.08	−.23	−.33
	(.06)	(.04)	(.05)
Capital-output	.42	.53	.53
	(.09)	(.09)	(.09)
Materials-output	.99	1.07	1.05
	(.04)	(.05)	(.06)
Labor-output	.70	.80	.72
	(.07)	(.07)	(.09)
Capital–technical change	.40	.20	.10
	(.13)	(.11)	(.11)
Materials–technical change	−.17	−.33	−.42
	(.07)	(.05)	(.06)
Labor–technical change	−.09	−.24	−.34
	(.11)	(.08)	(.13)

Note: Computed at the mean data point for each country. Approximate standard errors in parentheses.

proportionately less capital than labor. As expected, materials use expands approximately proportionately with capacity output. Technical change is capital using and materials and labor saving in all three countries.

The estimated disequilibrium effects are as expected. As the capacity utilization rate is reduced below unity, average cost increases and TFP declines. For example, for the United States, the TFP difference between production at capacity output (Q) and noncapacity output (q), calculated at the U.S. mean data point, is given by the equation

$$\text{(6)} \quad \log \text{TFP}(Q) - \log \text{TFP}(q) = -0.07 \log T_1 + 0.41(\log T_1)^2,$$

where T_1 is the capacity utilization rate. When capacity is underutilized, $q < Q$ and hence $T_1 < 1$. In this case, from (6), TFP (q) < TFP(Q); that is, total factor productivity declines.

3.4 Empirical Results: Rates of Growth of Average Cost, Total Factor Productivity, and Their Decomposition

Tables 3.6–3.10 below present the empirical results on costs and productivity that are the focus of this paper. Table 3.6 below contains our analysis of average production cost increases over the 1970–84 period and the 1970–80 and 1980–84 subperiods. The average annual percentage cost increases in a common currency (Canadian dollars) is contained in column 1. In Canadian dollars, over the 1970–84 period, average cost increased by an annual rate of 6.9% in Canada, 7.9% in the United States, and 7.2% in Japan. Both Canada and Japan improved their cost-competitive positions relative to the United States, but those improvements were not particularly large. The pattern of cost increases in each country's own currency tells a dramatically different story. The Japanese cost increase is only 2.5% per year, compared with 6.3% for the United States and 6.9% for Canada. The difference in the results is due to a substantial appreciation of the Japanese yen relative to the U.S. and Canadian dollars and a smaller appreciation of the U.S. dollar relative to the Canadian dollar. Table 3.5 contains the time path of the relevant exchange rates that had such a large impact on intercountry differences in average cost growth rates. The significant appreciation of the yen over the 1970–84 period, along with the Voluntary Export Restraints Agreements of 1981, has meant that the North American industries remained viable despite relative productivity stagnation (see below). This phenomenon has been even more important over the 1984–88 period, since the Japanese yen appreciated from 237 yen/$1U.S. to 130 yen/$1U.S.

The period 1970–80 was similar to 1970–84, with the above effects being even more pronounced. The 1980–84 period saw a narrowing of the rate of average cost increases, due to lower inflation rates in North America and, as we will see below, a narrowing of relative TFP growth rates.

Table 3.6 also contains our decomposition of the average cost increases. The decomposition in table 3.6 and subsequent tables is with respect to average costs as measured in the country's *own* currency. The formulas used to calculate the decomposition are developed in the technical appendix. The numbers in the "Sources of Increase" part of table 3.6 have the following interpretation. Consider the number 1.5 under the column labeled "Price of Labor" for Canada, 1970–84. If all variables affecting cost in Canada had remained constant at the geometric average of their 1970 and 1984 levels, *except for the price of labor*, unit production cost in Canada would have in-

Table 3.5 **Capacity Utilization Rates and Exchange Rates: Selected Years**

	Capacity Utilization Rate			Exchange Rate		
Year	Canada	United States	Japan	$CAN to $U.S.	Yen to $U.S.	Yen to $CAN
1970	.76	.74	1.00	.96	358	343
1972	.89	.96	1.00	1.01	303	306
1973	.94	1.04	1.03	1.00	271	271
1979	.77	.84	.98	.85	218	186
1980	.63	.62	1.01	.86	225	193
1982	.58	.58	.95	.81	248	201
1984	.85	.90	.95	.77	237	183

Table 3.6 Average Production Cost Increases and Their Sources[a]

	Average Annual Unit Production Cost Increase (%)			Sources of Increase (%)					
Country/ Time Period	Canadian Dollars	U.S. Dollars	Yen	Price of Labor	Price of Capital	Price of Materials	Scale Economies	Technical Change	Capacity Utilization
Canada:									
1970–84	6.9			1.5	1.3	5.2	−.7	−.3	−.3
1970–80	8.2			1.7	1.4	5.3	−.8	−.4	.9
1980–84	3.6			1.2	1.4	4.3	−.4	−.1	−3.0
United States:									
1970–84	7.9	6.3		1.7	1.2	4.6	−.2	−.8	−.3
1970–80	10.1	8.9		2.4	1.8	5.1	−.2	−1.1	.7
1980–84	2.6	.0		.4	.4	2.4	−.4	−.2	−2.7
Japan:									
1970–84	7.2		2.5	1.3	.6	3.6	−.5	−2.5	.0
1970–80	9.4		3.3	1.5	.6	5.0	−.6	−3.1	.0
1980–84	1.8		.5	.7	.4	.5	−.2	−.9	.1

[a] Costs are estimated costs derived from the cost function.

creased by 1.5% per annum because of the increase in the price of labor between 1970 and 1984. Similarly, the number −0.3 under the column labeled "Technical Change" in the first row of table 3.6 implies that if all variables except the technical change variable (stock of R&D) had been constant, Canadian unit production cost would have fallen by 0.3% per annum over the 1970–84 period. From the above description, it can be seen that what we have calculated in the "Sources of Increase" portion of table 3.6 is a set of discrete comparative statics results for variations in the exogenous variables affecting average production costs.

The major determinant of average cost increases over the 1970–84 period in all three countries has been increases in materials prices. Technical change has been the major source of cost reduction in the United States and Japan, whereas for Canada the major source of cost reduction was the realization of economies of scale associated with larger plant size.

As noted in the introduction, capacity utilization rates have varied considerably from year-to-year in the North American automotive industry. Utilization rates for selected years of our sample are presented in table 3.5. For the United States, capacity utilization (CU) has varied from a high of 1.04 in 1973 to a low of 0.58 in 1982. A similar variation has occurred for Canada. The Japanese industry's utilization rate is relatively constant over the whole period at nearly full utilization. The effect on cost of variations in CU in North America is most pronounced in the subperiods 1970–80 and 1980–84. For example, in the United States, average production costs would have increased by 0.7% per year between 1970–80 and decreased by 2.7% per year between 1980–84 due to the CU effect alone. Between 1980 and 1984, the increase in CU from 0.62 to 0.90 was the major force reducing average cost increases in the U.S. industry.

In order to analyze cost increases on a long-run basis, we present in table 3.7 the long-run equilibrium results, calculated from the estimated cost function, assuming capacity utilization rates are constant at the normal rate (unity) for all years for all three countries. As expected, Canadian and U.S. cost growth rates become less variable over subperiods. The U.S. cost growth advantage over Japan during 1980–84, which appeared in table 3.6, is reversed since it was entirely a capacity utilization phenomenon.

Table 3.8 presents the long-run equilibrium decomposition in a slightly different way. The components of TFP growth are aggregated (using eq. [B15] of the technical appendix with $T_1 = 1$) and compared with the factor price effects. This table portrays in a graphic way the fact that the Japanese auto industry has used productivity growth to keep unit production cost increases to a minimum, compared to North American producers. This effect was particularly pronounced during the 1970–80 period, but seems to have slackened off between 1980 and 1984.

Tables 3.9 and 3.10 examine changes in total factor productivity in the three countries. From 1970 to 1984 TFP grew by only 1.2% per year in Canada and

Table 3.7 **Unit Production Cost Increases and Their Sources: Long-Run Equilibrium**

	Average Annual Unit Production Cost Increase (%)			Sources of Increase (%)				
Country/ Time Period	Canadian Dollars	U.S. Dollars	Yen	Price of Labor	Price of Capital	Price of Materials	Scale Economies	Technical Change
Canada:								
1970–84	7.1			1.4	1.2	5.3	−.7	−.3
1970–80	7.4			1.5	1.2	5.7	−.8	−.4
1980–84	6.5			1.1	1.2	4.6	−.4	−.1
United States:								
1970–84	8.3	6.6		1.7	1.0	4.8	−.2	−.8
1970–80	9.5	8.2		2.3	1.4	5.6	−.2	−1.0
1980–84	5.4	2.7		.4	.3	2.6	−.4	−.2
Japan:								
1970–84	7.2		2.5	1.3	.6	3.6	−.5	−2.5
1970–80	9.5		3.3	1.5	.6	5.0	−.6	−3.1
1980–84	1.7		.4	.7	.4	.5	−.2	−.9

Table 3.8 **Unit Production Cost Increase: Long-Run Equilibrium**

Country	Average Annual Unit Production Cost Increase (%)			Sources of Increase (%)	
	Canadian Dollars	U.S. Dollars	Yen	Factor Prices	TFP Growth
Canada:					
1970–84	7.1			8.1	−.9
1970–80	7.4			8.6	−1.1
1980–84	6.5			7.0	−.4
United States:					
1970–84		6.6		7.7	−1.0
1970–80		8.2		9.5	−1.2
1980–84		2.7		3.3	−.5
Japan:					
1970–84			2.5	5.6	−3.0
1970–80			3.3	7.2	−3.8
1980–84			.4	1.5	−1.1

Table 3.9 **Total Factor Productivity (TFP) Growth**

Country	Average Annual TFP Growth Rate (%)	Percentage Contributions to Growth: Scale Economies	Capacity Utilization	Technical Change
Canada:				
1970–84	1.2	55	21	24
1970–80	.4	217	−241	124
1980–84	3.4	10	87	3
United States:				
1970–84	1.3	16	22	62
1970–80	.6	25	−115	190
1980–84	3.2	11	83	6
Japan:				
1970–84	3.0	17	−1	84
1970–80	3.8	17	0	83
1980–84	1.0	20	−8	88

Table 3.10 **Total-Factor Productivity (TFP) Growth: Long-Run Equilibrium**

Country	Average Annual TFP Growth Rate (%)	Percentage Contributions to Growth: Scale Economies	Technical Change
Canada:			
1970–84	.9	72	28
1970–80	1.1	69	31
1980–84	.4	84	16
United States:			
1970–84	1.0	21	79
1970–80	1.2	13	87
1980–84	.5	66	34
Japan:			
1970–84	3.0	17	83
1970–80	3.8	17	83
1980–84	1.1	18	82

1.3% in the United States, compared with a TFP growth rate of 3.0% for Japan. The difference is even more substantial during the 1970–80 period. On the other hand, TFP growth was considerably faster in the United States and Canada than in Japan during 1980–84. This latter result is quite misleading, since it is a phenomenon of variation in CU rates and points to the importance of accounting for variations in CU in a highly cyclical industry. In table 3.10, CU effects are removed and the underlying trends in efficiency are revealed. Over the 1970–84 period, North American long-run TFP growth rates were about 1% per annum, only about one-third of the TFP growth rate for Japan.

The contributions of the various sources of TFP growth over the 1970–84 period were very similar in the United States and Japan: approximately 80% of growth was due to technical change and 20% due to the growth of the average size of plant in the presence of increasing returns to scale. For Canada, 72% of TFP growth was due to scale economies and only 28% due to technical change.[7] The 1970–80 period was similar to the 1970–84 period. TFP grew somewhat more rapidly in all three countries with Japan maintaining a 3:1 edge. The 1980–84 period was quite different. TFP growth rates fell in all three countries, dramatically so in Japan. The 1980–84 results may not represent a long-run trend. First, the period is a fairly short one for calculations of this type. Second, this period saw very large modernization investments in all three countries, and during such periods the amount of productive capital stock tends to be overstated by perpetual inventory accumulation methods since obsolescence is not properly accounted for. On the other hand, if our 1980–84 results signal a long-run trend, the stagnation of productivity improvements will have far-reaching effects on the international motor vehicle industry.

Finally, it is of some interest to compare our TFP growth rate results with previous estimates. To our knowledge, there are no previous Canadian estimates. Previous estimates for the United States and Japan are presented in table 3.11. Conrad and Jorgenson (1985) and Jorgenson, Kuroda, and Nishimizu's (1987) TFP growth rates are below ours, and the difference for Japan is quite large. Part of the difference can be attributed to their adjustment of labor hours for educational attainment, which tends to increase the rate of growth of the labor input, thus lowering measured TFP growth. But this adjustment cannot account for the magnitude of the difference. Our results are

Table 3.11 **A Comparison of Estimates of Annual Average Total Factor Productivity Growth Rates (%)**

Time Period/ Country	Conrad and Jorgenson (1985)	Jorgenson, Kuroda, and Nishimizu (1987)	Griliches and Mairesse (1985)[a]	This Study[b]
1970–79:				
United States	.9			2.2
Japan	.6			3.5
1973–79:				
United States		−.2		1.2
Japan		1.4		3.6
1973–80:				
United States			−.7	−.4
Japan			4.4	3.9

[a] This paper examines transportation equipment industry only.

[b] Calculated using the Törnqvist index for purposes of comparison.

quite similar to those of Griliches and Mairesse (1985), who estimate TFP growth from a sample of individual firms drawn from the two-digit transportation equipment industry. Since 1973 was a peak and 1980 a trough in the North American automobile business cycle, the negative number for the United States is due to the effects on TFP of the decline in capacity utilization (from 1.04 to 0.62). Our estimates of the long-run underlying TFP growth rate over the period 1973–80 is + 1.1% per annum.

3.5 Conclusions

In this paper we have calculated and analyzed the motor vehicle industry's cost and productivity experience during the period 1970–84 in Canada, the United States, and Japan. Percentage cost increases in a common currency (Canadian dollars) differed less significantly than the increases in each country's own currency due to currency realignments. The appreciation of the Japanese yen masked the superior performance of the Japanese auto industry relative to the North American industries during the period under consideration.

We have emphasized the importance of taking account of variations in capacity utilization when analyzing TFP growth rates for an industry as cyclical as the motor vehicle industry. Failure to do so would have resulted in a 21% overestimate of long-run TFP growth in Canada and a 22% overestimate for the United States during the 1970–84 period (see table 3.9). More extreme problems would have occurred in subperiods. For example, over the 1970–80 period, ignoring capacity utilization effects would have resulted in a 241% underestimate of long-run TFP growth in Canada and a 115% underestimate for the United States.

The rate of growth of total-factor productivity in Japan over the 1970–84 period was three times as rapid as that which occurred in North America, which meant that Japan improved its relative long-run efficiency position by approximately 30 percentage points from 1970 to 1984. According to our analysis of productivity levels (Fuss and Waverman 1990), by 1984 Japanese producers had an 18% efficiency advantage over U.S. producers (at normal capacity utilization rates). On the other hand, there is some tentative evidence of a substantial slowdown in Japanese TFP growth rates during the 1980s, which, along with the continuing appreciation of the yen, places the North American industry in a much more competitive position at the close of the decade than was the case in the early 1980s.

Appendix A
Data Appendix

In this data appendix we provide a brief description of the sources and construction of data used in the empirical analysis. Greater detail can be found in

Fuss and Waverman (1991). The general data sources are the Annual Surveys (or Census) of Manufactures in each country. One problem with these data is the omission of a number of automotive-related production statistics from the annual surveys undertaken by the specific country's statistical office. Several relevant four-digit SIC codes are not classified to the Motor Vehicles Industries in the United States and Canada (e.g., automotive products foundries are classified to SIC 294 [foundries] in Canada; in the United States, automotive stampings are included in All Metal Stampings). These omissions affect our results to the extent that some bias is imparted if the omitted subindustries are significantly different from those included.

Nominal gross actual output data were taken from the central statistical surveys and converted to real actual output in constant dollars by applying the appropriate price deflators (available in Canada from Statistics Canada, in the United States, from the Bureau of Industrial Economics [BIE] and in Japan from the Bank of Japan).

Capacity output is real actual output divided by the capacity utilization rate (CU) (see below for the construction of CU). Average output per plant was computed as a weighted average (weighted by proportion of total output) of the average output in seven size classes. The weighting procedure was used so that the large number of plants in the smallest size classes would not distort the data. The "effective" number of plants is total output divided by average output per plant, and this number is used to compute cost per plant. The size-class data are available in each year for Canada and Japan. For the United States, these data are available only for census years, and the average plant size for other years was obtained by interpolation.

The output price deflators are indices that are normalized to unity in a particular year for each country. The same normalization occurs for materials and capital services prices. Because the cost function contains only zero- and first-order country-specific coefficients, the estimated characterization of the production process in terms of elasticities is invariant to the choice of the benchmark data set that is used to bridge the intercountry price indices to obtain absolute level comparisons. This is also true for country-specific rates of growth of average cost and total factor productivity, which are the topics of this paper. However, the data are also being used to make intercountry cost and productivity level comparisons, and so great care was exercised in calculating the benchmark data. The interested reader can find the details in Fuss and Waverman (1990, 1991). Of course the country-specific zero- and first-order regression coefficients do depend on the specific benchmark data set used to bridge the country-specific data.

Three inputs are used—materials, labor and capital. Materials price deflators were available for all three countries. The total compensation (rather than just the money wage) of labor has been calculated and hours worked estimated for production plus nonproduction workers. Real capital stock data were available for Canada from Statistics Canada, and for the United States from Norsworthy and Zabala (1983) and the Office of Business Analysis. Capital stock data had to be estimated for Japan using investment from the annual census and the perpetual inventory method.

The appropriate price of capital services is the ex ante neoclassical user cost of capital services $PK = QK \cdot (r + d)(1 - uz)/(1 - u)$, where QK is the capital asset price, r is the ex ante rate of return, d is the depreciation rate, u is the corporate tax rate, and z is the present value of the depreciation allowances for tax purposes on an investment of one unit of currency. The motor-vehicle-industry-specific capital service price series that were available for the United States had been estimated by the residual method, which is an inappropriate ex ante measure for such a highly cyclical industry. We have instead constructed a user cost of capital series by combining the rate of return and tax effects for U.S. total manufacturing (which would not be subject to such cyclical variations), which can be calculated from Norsworthy and Malmquist (1983), with the motor-vehicle-industry-specific capital asset price index, that is, PK (motor vehicles) = PK (manufacturing) · QK (motor vehicles) / QK (manufacturing). This construction implies that we are assuming that ex ante rates of return, depreciation rates, and tax effects for motor vehicles and manufacturing are equal in a particular year. We believe this assumption is preferred to the only other ones available to us—that ex ante and ex post rates of return are equal or tax effects are the same across countries. The Norsworthy Malmquist (NM) data are published only to 1977 and were updated to 1980 using internal U.S. Bureau of the Census data. The U.S. capital service price series was extrapolated to 1984, assuming no change in tax parameters. The capital service price for Japan is constructed in the same way as for the United States, except that the NM data are available only to 1978, and hence the extrapolation method is used for the period 1979–84. The motor vehicles asset price deflator was kindly provided by Masahiro Kuroda from his unpublished data base. For Canada, the method of combining the asset price for motor vehicles with manufacturing tax, rate of return, and depreciation data was utilized over the complete sample. Unpublished estimates of manufacturing user costs for 1961–81 were kindly provided to us by Michael Denny. These data were updated to 1984 using a Törnqvist aggregation of unpublished Economic Council of Canada estimates for durable and nondurable manufacturing sectors.

Capacity utilization (CU) rates were calculated from data for total vehicle assembly. For Japan, the count of motorcycles and other vehicles were value weighted so that fluctuations in motorcycle production would not distort the comparative data. Maximum (potential) output was measured in the United States and Canada from individual plant data as the maximum weekly nameplate output, and in Japan from more aggregate data as the maximum monthly output.

The "normal," or full CU rate was defined as the average utilization rate (ratio of actual to maximum output) for Japan 1969–80, since yearly CU rates were reasonably constant over that period. Actual CU rates were normalized so that this average rate was equal to unity.

For each country we have estimated a technological change indicator—the "capital stock" of R&D. This stock is constructed by converting annual R&D expenditures to a real capital stock utilizing the perpetual inventory method, the country-specific consumer price index (CPI), and a depreciation rate of 15%. Our data on R&D expenditures for Japan began in 1967. Therefore, we needed a benchmark R&D stock. We assumed that in 1967 the technology available to Japan could be represented by the R&D stock in North America, and we normalized the Canada, U.S., and Japan stock to unity in each country in 1967. By this construction we are estimating the effect of the change in the R&D stock on the change in costs, which is appropriate for an analysis of the growth rate of average cost and TFP. From another perspective, our R&D variable can be viewed as a method of tracing the country-specific, unexplained technical change. From this point of view, the variable is similar to a time trend, although it consistently outperformed a time trend in the regression analysis.

Technical Appendix

Equality of Total Factor Productivity and Cost Efficiency Growth Rates

$$C = \sum_{k=1}^{K} w_k \cdot X_k, \tag{B1}$$

where C is total cost, and X_k and w_k are quantities and prices of the kth input, respectively. Differentiating (B1) we obtain

$$dC = \sum_k w_k dX_k + \sum_k X_k dw_k, \tag{B2}$$

or

$$\frac{dC}{C} = \sum_k \left(\frac{w_k X_k}{C}\right)\frac{dX_k}{X_k} + \sum_k \left(\frac{w_k X_k}{C}\right)\frac{dw_k}{w_k}. \tag{B3}$$

Subtracting dq/q (proportionate change in actual output) from both sides of (B3) and rearranging yields

$$\frac{dC}{C} - \frac{dq}{q} - \sum_k s_k \frac{dw_k}{w_k} = -\left(\frac{dq}{q} - \sum s_k \frac{dX_k}{X_k}\right), \tag{B4}$$

where s_k is the cost share of the kth input in total cost.

Equation (B4) can be rewritten as

$$-[d\log C/q - \Sigma\, s_k\, d\log w_k] = d\log q - \Sigma\, s_k\, d\log X. \tag{B5}$$

The left-hand side of (B5) is the Divisia index of cost efficiency growth and the right-hand side is the Divisia index of total factor productivity (TFP) growth.

The Törnqvist Index of Cost Efficiency and the Translog Cost Function

The Törnqvist discrete approximation to the left-hand side of (B5) for the *i*th country is

$$\text{(B6)} \qquad \Delta\log CE_i = -[\Delta\log C_i/q_i - \sum_k \tfrac{1}{2}(s_{ki1} + s_{ki0})\,\Delta\log w_{ki}],$$

or

$$\begin{aligned} \log CE_{i1} - \log CE_{i0} = {} & -[(\log C_{i1}/q_{i1} - \log C_{i0}/q_{i0}) \\ & -\tfrac{1}{2}\sum_k (s_{ki1} + s_{ki0})(\log w_{ki1} - \log w_{ki0})], \end{aligned}$$

which is equation (2) in the text.

We can link the above index to the translog cost function in the following way. Suppose the cost function (1) is approximated by a translog cost function (a quadratic function in the logarithms of w_{it}, Q_{it}, and T_{it}) in which the zero- and first-order parameters differ across countries, but the second-order parameters are the same for each country. In that case the translog cost function will be of the form

$$\text{(B7)} \qquad \log C_{it} = G(\log w_{it}, \log Q_{it}, \log T_{it}, D)$$

where G is a quadratic function and D is a vector of country-specific dummy variables. Following Denny and Fuss (1983), we can apply the quadratic lemma to (B7) for the *i*th country and time periods 1 and 0 to obtain

$$\text{(B8)} \qquad \begin{aligned} \Delta\log C = {} & \log C_{i1} - \log C_{i0} \\ = {} & \tfrac{1}{2}\left(\frac{\partial G}{\partial D_i}\Big|_i + \frac{\partial G}{\partial D_i}\Big|_i\right)\left(D_i - D_i\right) \\ & + \tfrac{1}{2}\sum_k \left(\frac{\partial G}{\partial\log w_k}\Big| w_k = w_{ki1} + \frac{\partial G}{\partial\log w_k}\Big| w_k = w_{ki0}\right) \cdot \\ & \left[\log w_{ki1} - \log w_{ki0}\right] \\ & + \tfrac{1}{2}\left(\frac{\partial G}{\partial\log Q}\Big| Q = Q_{i1} + \frac{\partial G}{\partial\log Q}\Big| Q = Q_{i0}\right) \cdot \\ & \left(\log Q_{i1} - \log Q_{i0}\right) \\ & + \tfrac{1}{2}\sum_j \left(\frac{\partial G}{\partial\log T_j}\Big| T_j = T_{ji1} + \frac{\partial G}{\partial\log T_j}\Big| T_j = T_{ji0}\right) \cdot \\ & \left(\log T_{ji1} - \log T_{ji0}\right). \end{aligned}$$

Assuming price-taking behavior in factor markets and utilizing Shephard's lemma, (B8) can be written as

$$
\text{(B9)}\qquad
\begin{aligned}
\Delta\log C = {} & \tfrac{1}{2}\sum_k \left(s_{ki1} + s_{ki0}\right)\left(\log w_{ki1} - \log w_{ki0}\right) \\
& + \tfrac{1}{2}\left(\mathrm{ECQ}_{i1} + \mathrm{ECQ}_{i0}\right)\left(\log Q_{i1} - \log Q_{i0}\right) \\
& + \tfrac{1}{2}\sum_j \left(\mathrm{ECT}_{ji1} + \mathrm{ECT}_{ji0}\right)\left(\log T_{ji1} - \log T_{ji0}\right) \\
& + \Theta_{ii},
\end{aligned}
$$

where

$$
\text{(B10)}\qquad \Theta_{ii} = \tfrac{1}{2}\left(\frac{\partial G}{\partial D_i}\Big|i + \frac{\partial G}{\partial D_i}\Big|i\right)\cdot\left(D_i - D_i\right) = 0,
$$

where ECQ = elasticity of cost with respect to capacity output and
ECT_j = elasticity of cost with respect to the jth technological characteristic.

If we subtract $(\log Q_{i1} - \log Q_{i0})$ from both sides of equation (B9) we obtain the decomposition of cost per unit capacity output growth used in the graphical analysis:

$$
\text{(B11)}\qquad
\begin{aligned}
\Delta\log (C/Q) = {} & \tfrac{1}{2}\sum_k \left(s_{ki1} + s_{ki0}\right)\left(\log w_{ki1} - \log w_{ki0}\right) \\
& + \tfrac{1}{2}\left(\mathrm{ECQ}_{i1} + \mathrm{ECQ}_{i0} - 2\right)\left(\log Q_{i1} - \log Q_{i0}\right) \\
& + \tfrac{1}{2}\sum_j \left(\mathrm{ECT}_{ji1} + \mathrm{ECT}_{ji0}\right)\left(\log T_{ji1} - \log T_{ji0}\right).
\end{aligned}
$$

The decomposition (B11) is the translog specification corresponding to table 3.1 in the text. The correspondence is presented in table 3.B1.

TFP growth and its decomposition corresponding to table 3.2 can be obtained by subtracting the factor price effect from both sides of (B11) and mul-

Table 3B.1 **Decomposition of Cost per Unit Capacity Output Growth**

Effect	Translog Specification	Table 3.1 Representation
Factor price k	$\tfrac{1}{2}(s_{ki1} + s_{ki0})(\log w_{ki1} - \log w_{ki0})$	$C_B - C_O$ and $C_C - C_B$
Scale economies	$\tfrac{1}{2}(\mathrm{ECQ}_{i1} + \mathrm{ECQ}_{i0} - 2)(\log Q_{i1} - \log Q_{i0})$	$C_D - C_C$
Capacity utilization	$\tfrac{1}{2}(\mathrm{ECT}_{1i1} + \mathrm{ECT}_{1i0})(\log T_{1i1} - \log T_{1i0})$	$C_E - C_D$
Technical change	$\tfrac{1}{2}(\mathrm{ECT}_{2i1} + \mathrm{ECT}_{2i0})(\log T_{2i1} - \log T_{2i0})$	$C_1 - C_E$

Table 3B.2 **TFP Growth and Its Decomposition**

	Translog Specification	Table 3.2 Representation
TFP growth (in terms of capacity output)	$-\{\Delta\log (C/Q) - \frac{1}{2}\sum_k [s_{ki1} + s_{ki0}][\log w_{ki1} - \log w_{ki0}]\}$	$-(C_1 - C_C)$
Effect:		
Scale economies	$-\frac{1}{2}(\mathrm{EC}Q_{i1} + \mathrm{EC}Q_{i0} - 2)(\log Q_{i1} - \log Q_{i0})$	$-(C_D - C_C)$
Capacity utilization	$-\frac{1}{2}(\mathrm{EC}T_{1i1} + \mathrm{EC}T_{1i0})(\log T_{1i1} - \log T_{1i0})$	$-(C_E - C_C)$
Technical change	$-\frac{1}{2}(\mathrm{EC}T_{2i1} + \mathrm{EC}T_{2i0})(\log T_{2i1} - \log T_{2i0})$	$-(C_1 - C_E)$

tiplying both sides by minus one. The correspondence is presented in table 3.B2.

If instead of subtracting $\Delta\log Q_i$ we subtract $(\log q_{i1} - \log q_{i0})$ from both sides of equation (B9) and recall that $q_{it} = Q_{it} \cdot T_{1it}$, $t = 0,1$, then (B9) provides a decomposition of the actual average cost increase between periods 1 and 0 for country i

$$\text{(B12)}\quad \begin{aligned}\Delta\log (C/q) = {} & \tfrac{1}{2}\sum_k \left(s_{ki1} + s_{ki0}\right)\left(\log w_{ki1} - \log w_{ki0}\right) \\ & + \tfrac{1}{2}\left(\mathrm{EC}Q_{i1} + \mathrm{EC}Q_{i0} - 2\right)\left(\log Q_{i1} - \log Q_{i0}\right) \\ & + \tfrac{1}{2}\left(\mathrm{EC}T_{1i1} + \mathrm{EC}T_{1i0} - 2\right)\left(\log T_{1i1} - \log T_{1i0}\right) \\ & + \tfrac{1}{2}\left(\mathrm{EC}T_{2i1} + \mathrm{EC}T_{2i0}\right)\left(\log T_{2i1} - \log T_{2i0}\right).\end{aligned}$$

The decomposition (B12) is the formula used to obtain the average cost results contained in tables 3.6 and 3.7. For example, the scale-economies effect over the period 1970–84 is calculated as $\{[\exp(x)]^{1/14} - 1\} \cdot 100$ where

$$\text{(B13)}\quad x = \tfrac{1}{2}\,(ECQ_{i,1984} + ECQ_{i,1970} - 2)(\log Q_{i,1984} - \log Q_{i,1970}).$$

The translog (Törnqvist) index of the growth in cost efficiency or total factor productivity between periods 0 and 1 for country i is obtained from (B12) by subtracting the factor price effects from both sides of the equation and multiplying the result by -1:

$$\text{(B14)}\quad \begin{aligned}\log CE_{i1} - \log CE_{i0} = \log TFP_{i1} - \log TFP_{i0} = {} & -[\Delta\log(C/q) \\ & - \tfrac{1}{2}\sum_k (s_{ki1} + s_{ki0})(\log w_{ki1} - \log w_{ki0}),\end{aligned}$$

and

$$\begin{aligned}\log CE_{i1} - \log \mathrm{CE}_{i0} = {} & -\tfrac{1}{2}(ECQ_{i1} + ECQ_{i0} - 2)(\log Q_{i1} - \log Q_{i0}) \\ & - \tfrac{1}{2}\,(ECT_{1i1} + ECT_{1i0} - 2)(\log T_{1i1} - \log T_{1i0}) \\ & - \tfrac{1}{2}\,(ECT_{2i1} + ECT_{2i0})(\log T_{2i1} - \log T_{2i0}).\end{aligned}$$

Equation (B14) is just equation (2) in the text. Equation (B15) provides the decomposition of the translog index of efficiency growth into its sources. This formula underlies the results presented in tables 3.9 and 3.10. For example, the average annual growth rate of TFP for country i over the period 1970–84 is given by $\{[\exp(\Delta\log \mathrm{CE}_i)]^{1/14} - 1\} \cdot 100$. The percentage contribution of scale economies is calculated as $(x/y) \cdot 100$ where

$$x = -\tfrac{1}{2}(\mathrm{EC}Q_{i1} + \mathrm{ECQ}_{i0} - 2)(\log Q_{i1} - \log Q_{i0}),$$

and

$$y = \Delta\log \mathrm{CE}_i.$$

Notes

1. Reasonably accessible (nontechnical) discussions of the cost function approach to production analysis can be found in Baumol (1977), Varian (1984) and Fuss (1987). Fuss and McFadden (1978) provide a more technically difficult and detailed treatment. The rationale for including the capacity utilization rate as an argument in the cost function is developed in Fuss and Waverman (1991).

2. In the empirical analysis, materials constitutes a third factor of production. For simplicity it is not considered explicitly at this stage of the exposition.

3. The most common index of the state of technology is a time trend. In this paper we use the real net stock of R&D expenditures to index the state of technology.

4. The cost efficiency expression can be calculated from (2) by noting that log $(C_i/Q_i) = \log (C_i/q_i) + \log T_{1i}$.

5. The cost function that was actually estimated is not quite the standard translog function since it contains several third-order terms. These terms were necessary in order to insure that the short-run, long-run effects generated by including capacity utilization as an argument of the cost function satisfied the Viner-Wong envelope theorem (Viner 1952). See Fuss and Waverman (1990, 1991) for details.

6. An output mix variable (the average weight of automobiles produced in a particular country in a specific year) was added to the list of explanatory variables to control for the bias in the calculation of real output, which occurs when the price = marginal cost assumption is violated (as it is in this industry) and the mix of vehicles (by size class) is changing over time. Between 1970 and 1984 there was a trend to the production of smaller vehicles in North America and larger vehicles in Japan. The average cost and TFP growth rates presented below have been corrected for the bias using the results of the cost function estimation. For further details see Fuss and Waverman (1990).

7. The sources of growth columns in tables 3.9 and 3.10 are organized according to conventional growth accounting procedures, in contrast with tables 3.6–3.8. They measure the proportions of TFP growth that can be attributed to the various effects.

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