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PRODUCTIVITY GROWTH IN THE AUTOMOBILE INDUSTRY, 1970-1980: A COMPARISON OF CANADA, JAPAN AND THE UNITED STATES

Melvyn Fuss

Leonard Waverman

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ABSTRACT

In this paper we calculate and analyze the automobile industries cost and productivity experience during the 1970's in Canada, the U.S. and Japan. Utilizing an econometric cost function methodology, we are able to isolate the major source of short-run disequilibrium in this industry - variations in capacity utilization - and analyze its effects on cost and total factor productivity (TFP) gross. This is achieved through a novel application of the Viner-Wong envelope theorem, which allows us to track short-run behavior utilizing what is essentially a long-run cost function.

Two striking empirical results emerge. First, TFP grew much faster in the Japanese automobile industry (4.3% annum) than in the Canadian (1.4%) and U.S. (1.6%) industries. Second, the importance in analyzing variations in capacity utilization is confirmed by the fact that failure to correct for this source of productivity change would have led to a 31% underestimate of long-run TFP growth in Canada and a 37% underestimate for the United States.

Melvin A. Fuss
Department of Economics
University of Toronto
Toronto, Canada
M5S 1A1

Leonard Waverman
Department of Economics
University of Toronto
Toronto, Canada
M5S 1A1

1. Introduction

The automobile industry is perhaps the most outstanding example of the Japanese competitive threat to North American manufacturing. The Japanese production cost advantage has been estimated to be as high as $2,000 per vehicle (Abernathy and Harbour (1981), Abernathy, Clark and Kantrow (1983), Federal Trade Commission (1983)). These studies attribute a substantial proportion of the cost advantage to superior productivity performance by Japanese automobile manufacturers.

This paper differs from the earlier studies cited above in a number of ways. First, we will be estimating comparative growth rates of unit costs and productivity rather than comparing levels at a point in time.[1] Second, previous studies of U.S.-Japanese automobile costs have been essentially accounting studies, and have not employed more rigorous analytical methods. In this study, we utilize an econometric cost function and the decomposition analysis proposed by Denny and Fuss (1983) to measure the growth in unit cost and productivity and to determine the sources of growth. This methodology permits us to overcome two major shortcomings of previous studies - the inability to adequately disentangle factor price effects from efficiency effects, and the inability to account correctly for short-run disequilibrium. The source of disequilibrium that we are concerned with in this paper is due to variations in capacity utilization. Variations in capacity utilization affect both unit costs and total factor productivity. Accounting for capacity utilization effects is particularly crucial in the automobile industry, an industry characterized by quasi-fixed factors (capital and part of labour) and product-specific manufacturing facilities. Hence swings in consumer tastes among different products can lead to variations in capacity utilization which may greatly affect measured unit cost and productivity growth. In fact, the empirical results presented below indicate that long-run total factor productivity growth during the 1970's would have been underestimated by 37% in the United States and 31% in Canada had capacity utilization effects not been accounted for. This is due primarily to the very low rates of capacity utilization in the North American automobile industry in 1980, the last year of our sample.

Even after correcting for capacity utilization differences, the Japanese productivity "miracle" is evident from our results for automobile production. During the 1970's total factor productivity in the Japanese automobile industry grew at an average rate of 4.3% per annum. By way of contrast, the Canadian and U.S. automobile industries experienced average per annum TFP growth rates of only 1.4% and 1.6% respectively, about 1/3 of the Japanese rates. The large difference between the TFP growth rates of the U.S. and Japanese automobile industries is in sharp contrast to Norsworthy and Malmqvist's (1983) results for total manufacturing, where the Japanese advantage was much less pronounced. The comparatively 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 2.9% annual rate for Japanese automobile production, whereas long-run average cost increased at a 7.6% rate in Canada and at a 7.8% rate in the U.S.

As noted previously, these empirical results are obtained from an estimated econometric cost function and a decomposition analysis. Sections 2 and 3 present the formal model underlying the empirical results. Included in Section 3 is a discussion of the way in which capacity utilization effects are captured through a somewhat novel application of the Viner-Wong envelope result. The specific empirical results are contained in Sections 4 and 5. In Section 6 we conclude the paper with some summary remarks.

2. The Cost Function Approach to the Analysis of Cost and Total Factor Productivity Differences

2.1 Cost Comparisons - A Decomposition Analysis

Utilizing the duality between cost and production under the assumption of cost-minimizing behaviour, we specify that the automobile production process can be represented indirectly by the cost function

$$C_{it} = G_{it}(\underline{w}_{it}, \underline{Q}_{it}, \underline{T}_{it}) \qquad (2.1)$$

where C_{it} is the total cost of production in country i at time t, $\underline{w}_{it}$ is a vector of factor prices, $\underline{Q}_{it}$ is a vector of outputs and $\underline{T}_{it}$ is a vector of technological conditions which 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 expenditures (a proxy for technical change) and capacity utilization. The use of this characteristics approach was proposed by McFadden (1978) and has been applied to telecommunications [Denny, et al. (1981a, b)], trucking [Spady and Friedlaender (1978), Kim (1984)] and U.S. automobile production [Friedlaender, Winston and Wang (1983)]. The logarithm of the cost function (2.1) will be appproximated by a quadratic function in the logarithms of $\underline{w}_{it}$, $\underline{Q}_{it}$, $\underline{T}_{it}$ and $\underline{D}$; i.e.,

$$\log C_{it} = G(\log \underline{w}_{it}, \log \underline{Q}_{it}, \log \underline{T}_{it}, \underline{D}) \qquad (2.2)$$

where G is a quadratic function and $\underline{D}$ is a vector of country-specific dummy variables. Applying the Quadratic Lemma[2] to (2.2) yields

$$\Delta \log C = \log C_{is} - \log C_{0t}$$

$$= \frac{1}{2}\left[\frac{\partial G}{\partial D_i}\bigg|_i + \frac{\partial G}{\partial D_i}\bigg|_0\right] \cdot [D_i - D_0]$$

$$+ \frac{1}{2}\sum_k \left[\frac{\partial G}{\partial \log w_k}\bigg|_{w_k = w_{kis}} + \frac{\partial G}{\partial \log w_k}\bigg|_{w_k = w_{k0t}}\right] \cdot [\log w_{kis} - \log w_{k0t}]$$

$$+ \frac{1}{2}\sum_j \left[\frac{\partial G}{\partial \log Q_j}\bigg|_{Q_j = Q_{jis}} + \frac{\partial G}{\partial \log Q_j}\bigg|_{Q_j = Q_{j0t}}\right] \cdot [\log Q_{jis} - \log Q_{j0t}]$$

$$+ \frac{1}{2}\sum_l \left[\frac{\partial G}{\partial \log T_l}\bigg|_{T = T_{lis}} + \frac{\partial G}{\partial \log T_l}\bigg|_{T = T_{l0t}}\right] \cdot [\log T_{lis} - \log T_{l0t}] \qquad (2.3)$$

where i indexes the country

t,s index the time period

k indexes the factors of production

j indexes outputs

l indexes characteristics

$D_i = 1$ if the observation is in country $i \neq 0$

$= 0$ otherwise

and country 0 is the "reference" or "base" country. Assuming price-taking behaviour in factor markets and utilizing Shephard's Lemma, (2.3) can be written as

$$\Delta\log C = \frac{1}{2}\sum_{k} [S_{kis} + S_{k0t}][\log w_{kis} - \log w_{k0t}]$$

$$+ \frac{1}{2}\sum_{j} [ECQ_{jis} + ECQ_{j0t}][\log Q_{jis} - \log Q_{j0t}]$$

$$+ \frac{1}{2}\sum_{l} [ECT_{lis} + ECT_{l0t}][\log T_{lis} - \log T_{l0t}]$$

$$+ \theta_{i0} \tag{2.4}$$

where

$$\theta_{i0} = \frac{1}{2}\left[\left.\frac{\partial G}{\partial D_i}\right|_{i} + \left.\frac{\partial G}{\partial D_i}\right|_{0}\right] \cdot [D_i - D_0] \tag{2.5}$$

ECQ = elasticity of cost with respect to output

ECT = elasticity of cost with respect to the technological characteristic

Denny et al. (1981b) have shown that the appropriate definition of the difference in the logarithm of "average" cost for a multiple output technology[3] is

$$\Delta\log \text{"average" cost} = \Delta\log C - \Delta\log Q^{c} \tag{2.6}$$

where $\Delta\log Q^{c} = \frac{1}{2}\sum_{j}\left[\frac{(ECQ_{jis} + ECQ_{jot}}{\frac{1}{2}\sum_{j}(ECQ_{jis} + ECQ_{j0t})}\right]$

$$.[\log Q_{jis} - \log Q_{j0t}]$$

$$= [\tfrac{1}{2}(ECQ_{i} + ECQ_{0})]^{-1}$$

$$.\{\tfrac{1}{2}\sum_{j}[ECQ_{jis} + ECQ_{j0t}]$$

$$\cdot\,[\log Q_{jis} - \log Q_{j0t}]\}$$

and $ECQ_i = \sum_j ECQ_{jis}$ [4]

Equation (2.4) becomes

$$\begin{aligned}\Delta\log\,(C/Q^c) = {} & \frac{1}{2}\sum_k [S_{kis} + S_{k0t}].[\log w_{kis} - \log w_{k0t}] \\ & + \frac{1}{2}\,(ECQ_i + ECQ_0 - 2)\ .\ \Delta\log Q^c \\ & + \frac{1}{2}\sum_l [ECT_{lis} + ECT_{l0t}].[\log T_{lis} - \log T_{l0t}] \\ & + \theta_{i0} \end{aligned} \tag{2.7}$$

For any specific country, $i=0$ and $\theta_{i0}=0$; thus the index of average cost difference between time t and time s is given by

$$\begin{aligned}\Delta\log\,(C/Q^c) = {} & \frac{1}{2}\sum_k [S_{ks} + S_{kt}].[\log w_{ks} - \log w_{kt}] \\ & + \frac{1}{2}\,[ECQ_s + ECQ_t - 2].\Delta\log Q^c \\ & + \frac{1}{2}\sum_l [ECT_{ls} + ECT_{lt}].[\log T_{ls} - \log T_{lt}] \end{aligned} \tag{2.8}$$

where the country index is suppressed for simplicity. If $s=t+1$, equation (2.8) is just the formula for the decomposition of yearly proportionate changes in average cost. The rate of total factor productivity growth between time periods t and s is given by

$$\begin{aligned}TFP_{t,s} = -\{\Delta\log\,(C/Q^c) - \frac{1}{2}\sum_k [S_{ks} + S_{kt}] & \\ .[\log w_{ks} - \log w_{kt}\} & \end{aligned} \tag{2.9}$$

If $s=t+1$, equation (2.9) is just the Tornqvist formula for calculating the annual TFP growth rate from factor price data.

Rearranging equation (2.9), we obtain an alternative equation for $\Delta \log (C/Q^c)$:

$$\Delta \log (C/Q^c) = \frac{1}{2} \sum [S_{ks} + S_{kt}].[\log w_{ks} - \log w_{kt}] - TFP_{t,s} \tag{2.10}$$

Combining (2.8) and (2.9) we obtain an epxression for TFP in terms of efficiency sources:

$$\begin{aligned} TFP_{t,s} = &- [\frac{1}{2} (ECQ_s + ECQ_t - 2).\Delta \log Q^c \\ &+ \frac{1}{2} \sum_{l} (ECT_{ls} + ECT_{lt})(\log T_{lt} - \log T_{lt})] \end{aligned} \tag{2.11}$$

Equations (2.8), (2.10) and (2.11) provide the formulae for decomposing average (unit) cost differences and total factor productivity differences into their various sources.

Consider equation (2.8). The left hand side is the average cost difference. This difference is due to differences in factor prices (the first row on the right hand side), the effects of scale economies (the second row), and the effects of technological characteristics (the third row). Now consider equation (2.10). The average cost difference between two points in time is due to differences in factor prices (the first term), and total factor productivity growth between the two periods (the second term). Finally, consider equation (2.11). Total factor productivity growth over time within a country is due to output growth in the presence of scale economies (the first row), and changes in technological conditions (the second row).

2.2 Estimation of the Cost Function

The cost function (2.1) is approximated by a quadratic function of the form (2.2). Writing out (2.2) in detail for the i-th country yields

$$
\begin{aligned}
\log C_{it} = \alpha_0 + \alpha_{0i} D_i &+ \sum_k (\alpha_k + \alpha_{ki} D_i) \log w_{kit} \\
&+ \sum_j (\beta_j + \beta_{ji} D_i) \log Q_{jit} \\
&+ \sum_l (\theta_l + \theta_{li} D_i) \log T_{lit} \\
&+ \frac{1}{2} [\sum_k \delta_{kk} (\log w_{kit})^2 + \sum_j \mu_{jj} (\log Q_{ijt})^2 \\
&\qquad + \sum_l \phi_{ll} (\log T_{lit})^2] \\
&+ \sum_{\substack{k \\ k<m}} \sum_m \delta_{km} \log w_{kit} \log w_{mit} \\
&+ \sum_{\substack{j \\ j<n}} \sum_n \mu_{jn} \log Q_{jit} \log Q_{nit} \\
&+ \sum_{\substack{l \\ l<p}} \sum_p \phi_{lp} \log T_{lit} \log T_{pit} \\
&+ \sum_k \sum_j \lambda_{kj} \log w_{kit} \log Q_{jit} \\
&+ \sum_k \sum_l \lambda_{kl} \log w_{kit} \log T_{lit}
\end{aligned}
$$

$$+ \sum_j \sum_l \tau_{jl} \log Q_{jit} \log T_{lit} \tag{2.12}$$

Utilizing Shephard's Lemma results in the cost share equations

$$S_{kit} = \alpha_k + \alpha_{ki} D_i + \delta_{kk} \log w_{kit} + \sum_{m \neq k} \delta_{km} \log w_{mit}$$

$$+ \sum_j \lambda_{kj} \log Q_{jit} + \sum_l \Lambda_{kl} \log T_{lit} \qquad k = 1,\ldots,K \tag{2.13}$$

Estimates of the parameters of the system are obtained by estimating simultaneously (using maximum likelihood techiniques) the cost function (2.12) and K-1 equations from (2.13), imposing the constraints

$$\sum_k \alpha_k = 1, \quad \sum_k \alpha_{ki} = 0, \quad \sum_m \delta_{mk} = 0, \quad \delta_{mk} = \delta_{km},$$

$$\sum_k \lambda_{kj} = 0, \quad \sum_k \Lambda_{kl} = 0, \quad \sum_k \alpha_{ki} = 0, \quad \mu_{jn} = \mu_{nj},$$

$$\phi_{lp} = \phi_{pl} \tag{2.14}$$

2.3 Production Characteristics Obtained from the Cost Function

(i) Factor Substitution

The own factor price elasticity of demand (outputs held constant) is given by

$$E_{kk} = \frac{1}{S_k} [\delta_{kk} - S_k + s_k^2] \tag{2.15}$$

The Allan-Uzawa elasticity of substitution is given by

$$\sum_{km} = \frac{1}{S_k S_m} [\delta_{km} + S_k S_m] \tag{2.16}$$

(ii) Scale Economies

The scale elasticity is given by

$$SE = CE^{-1} = [\sum ECQ_j]^{-1} \tag{2.17}$$

where CE = the overall cost elasticity, and

$$\begin{aligned} ECQ_j = \frac{\partial \log C}{\partial \log Q_j} &= \beta_j + \sum_i \beta_{ji} D_i + \sum_n \mu_{jn} \log Q_n \\ &+ \sum_k \lambda_{kj} \log w_k \\ &+ \sum_l \tau_{jl} \log T_l \end{aligned} \tag{2.18}$$

(iii) Technological Conditions

The elasticity of cost with respect to the technological condition T_l can be obtained as

$$\begin{aligned} ECT_1 = \frac{\partial \log C}{\partial \log T_l} &= \theta_1 + \sum_i \theta_{li} D_i + \sum_p \phi_{lp} \log T_l \\ &+ \sum_k \Lambda_{kl} \log w_k \\ &+ \sum_j \tau_{jl} \log Q_j \end{aligned} \tag{2.19}$$

3. Incorporating Capacity Utilization Effects into the Cost Function - An Application of the Viner-Wong Envelope Theorem

As noted in the introduction, the automobile industry is characterized by quasi-fixed factors and yearly fluctuations in demand for its products. These features result in variations in capacity utilization which cannot be captured by a long-run equilibrium model. There are two possible approaches to this problem. First, a variable cost function with exogenous quasi-fixed factors could be specified and capacity utilization rates determined endogenously. An example of such an approach is Berndt and Fuss (1982). Second, capacity utilization, rather than the quasi-fixed factors, could be treated as exogenous. In this case the demands for quasi-fixed factors are determined endogenously.[5] An example of this second approach is Cowing and Stevenson (1981). While we intend to pursue the first approach in subsequent research, in this paper we adopt the second approach. This particular approach is likely to be successful when plants are designed, ex ante, to produce a "normal" flow of output which can be relatively easily measured. The major components of the automobile industry-vehicle assembly and the manufacture of engines, transmissions and transaxles satisfy this requirement.[6] Specifying capacity utilization rather than the levels of quasi-fixed factors as exogenous has two advantages. One, the identity of the quasi-fixed factors does not need to be determined a priori. Two, the analysis can proceed without the assumption that the quasi-fixed factors are fixed in the short run.[7]

The existence of capacity utilization as an argument of the cost function implies that the output argument should be capacity output.

Capacity output should be thought of as that flow of output per unit time which is viewed as "normal" by the firm, in the sense that if the output flow is sustained over time the firm has no incentive in the long run to adjust the level of its quasi-fixed factors. Normal capacity utilization then occurs when actual and designed (normal) output flows per unit time are equal. Hence it is natural to index capacity utilization so that it is unity when the actual output flow is at its normal rate.

Output increases which affect costs can occur in two ways. Existing capacity can be utilized more intensively, or capacity can be increased, utilization held constant. In this setting the Viner-Wong envelope result between short-run and long-run average costs (Viner (1952)) implies a set of constraints on the parameters of the translog cost function which are developed below.

Before proceeding to a detailed analysis of the envelope theorem, it is convenient to specify the actual arguments of the cost function used in the empirical analysis. The exogenous variables were specified as follows:

input prices (K=3) - capital (1); materials (2); labour (3)
outputs (J=1) - single output, constant dollar capacity (normal or designed) production of vehicles and parts
technological conditions (L=3) - capacity utilization (1); technological change proxy index-index of real stock of R & D expenditures (2); index of product mix (3)[8]

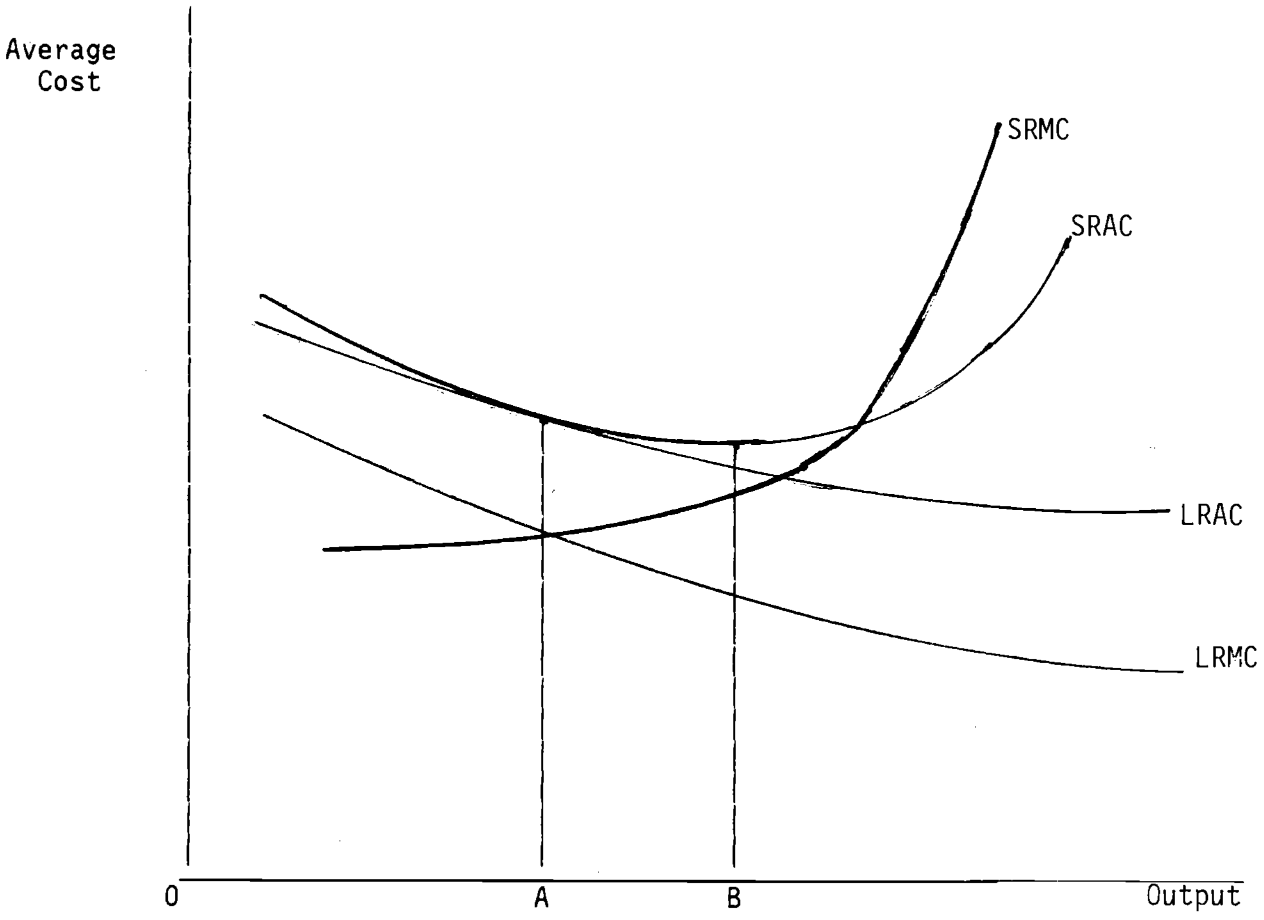
The envelope theorem is satisfied if the cost-normal output and cost-capacity utilization elasticities satisfy the following relationships:

$$\begin{aligned} &ECT_1 = ECQ_1, \text{ normal capacity utilization} \\ &ECT_1 < ECQ_1, \text{ below normal capacity utilization} \\ &ECT_1 > ECQ_1, \text{ above normal capacity utilization} \end{aligned} \tag{3.1}$$

where ECT_1 is the cost-capacity utilization elasticity and ECQ_1 is the cost-capacity output elasticity.

The relationship (3.1) is obvious for the case of long-run constant returns to scale, once it is recognized that ECT_1 is just the output elasticity of the short-run average cost curve[9] and ECQ_1 is the output elasticity of the long-run curve (equal to unity). For the case of increasing returns to scale, consider Figure 3.1. At the normal capacity utilization rate (output level OA), short-run marginal cost (SRMC) equals long-run marginal cost (LRMC) and short-run average cost (SRAC) equals long-run average cost (LRAC). Since $ECQ_1 = \frac{LRMC}{LRAC}$ and $ECT_1 = \frac{SRMC}{SRAC}$; $ECQ_1 = ECT_1$. Now suppose output is expanded to OB. If output expansion occurs with designed (normal) output Q^N constant, movement is along the SRAC curve (actual output Q^A increasing) and capacity utilization is above normal. If output expansion occurs with capacity utilization (T_1) constant at the normal rate, then the movement is along the LRAC curve (as Q^N increases). From Figure 3.1 it can be seen that for output expansion beyond OA, SRAC is falling

FIGURE 3.1



The Envelope Theorem and Capacity Utilization less rapidly than LRAC, so

$$\frac{\partial SRAC}{\partial Q} > \frac{\partial LRAC}{\partial Q} \qquad (3.2)$$

(where $\frac{\partial SRAC}{\partial Q}$, $\frac{\partial LRAC}{\partial Q} < 0$)

Inequality (3.2) can be manipulated into the form

$$(ECT_1 - 1) > \frac{SRTC}{LRTC} \cdot (ECQ_1 - 1)^{10} \qquad (3.3)$$

where SRTC and LRTC are short and long-run total costs respectively. Since SRTC > LRTC it follows that $ECT_1 > ECQ_1$.

Similarly, for output contraction below OA, it is the case that $\frac{\partial SRAC}{\partial Q} < \frac{\partial LRAC}{\partial Q}$, which implies that $ECT_1 < ECQ_1$. Hence relationship (3.1) has been demonstrated for the case of increasing returns to scale. An analogous argument exists for the case of decreasing returns to scale.

In order to develop the parameter constraints implied by the envelope theorem, recall that the capacity utilization rate was indexed so that it equals unity at the normal utilization rate. <u>When capacity utilization is at the normal rate</u>, the elasticities can be written as

$$ECT_1 = \theta_1 + \sum_i \theta_{1i} D_i + \phi_{12} \log T_2 + \phi_{13} \log T_3$$

$$+ \sum_k \Lambda_{k1} \log w_k + \tau_{11} \log Q_1^N \qquad (3.4)$$

$$ECQ_1 = \beta_1 + \sum_i \beta_{1i} D_i + \mu_{11} \log Q_1^N + \sum_k \lambda_{k1} \log w_k$$

$$+ \tau_{12} \log T_2 + \tau_{13} \log T_3 \qquad (3.5)$$

since $\log T_1 = 0$; and where Q^N_1 = capacity output.

For the left hand sides of (3.4) and (3.5) to be equal for all values of the exogenous variables, the following parameter constraints must be imposed:

$$\begin{aligned} &\theta_1 = \beta_1 \\ &\theta_{1i} = \beta_{1i} \qquad i = 1,2 \\ &\phi_{12} = \tau_{12} \\ &\Lambda_{k1} = \lambda_{k1} \qquad k = 1,2,3 \\ &\tau_{11} = \mu_{11} \end{aligned} \qquad (3.6)$$

When the equalities (3.6) are imposed, $ECT_1 - ECQ_1 =$ $(\phi_{11} - \tau_{11}) \cdot \log T_1$. Hence for the envelope <u>inequalities</u> in (3.1) to hold, it must be the case that $\phi 1_1 > \tau_{11}$.

Unfortunately, imposition of the envelope theorem renders the second order translog function less flexible than is desired. Since $\frac{\partial S_{kt}}{\partial \log T_1} = \Omega_{k1} = \lambda_{k1} = \frac{\partial S_{kt}}{\partial \log Q_1}$, factor cost shares change to the same extent when output increases, independent of whether the output increase is due to increased capacity utilization or increased capacity. Given the quasi-fixed nature of capital, capital cost shares will increase more (and other input shares less) when capacity utilization increases compared to capacity increases. To permit this possibility, third order terms must be added to the cost function. A parsimonious, sufficiently flexible specification is obtained by adding terms of the form

$$\frac{1}{6} \sum_{k=1,2,3} \sum_{i=1} \sum_{j=1} \rho_{kij} \log w_k \log T_i \log T_j$$

$$= \frac{1}{2} \sum_{k=1,2,3} \rho_{k11} \log w_k (\log T_1)^2 \qquad (3.7)$$

to the cost function.[11] As a result of (3.7), a term of the form

$$\frac{1}{2} \rho_{k11} (\log T_1)^2 \qquad (3.8)$$

is added to the k-th cost share equation.

The addition of (3.7) to the cost function implies that the allocation formulas of section 2 must also be altered. By applying the theoretical framework developed by Denny and Fuss (1983), it can be shown that an interaction term of the form

$$\frac{1}{2} \sum_{k} \rho_{k11} [\log w_{ks} - \log w_{kt}][\log T_{1s} - \log T_{1t}]^2 \qquad (3.9)$$

must be added to the right hand side of the decomposition formulas (2.8) and (2.11). Equation (2.8) becomes

$$\begin{aligned}\Delta\log (C/Q^c) = {} & \frac{1}{2} \sum_{k} [S_{ks} + S_{kt}].[\log w_{ks} - \log w_{kt}] \\ & + \frac{1}{2} (ECQ_s + ECQ_t - 2].\Delta\log Q^c \\ & + \frac{1}{2} \sum_{1} [ECT_{1s} + ECT_{1t}].[\log T_{1s} - \log T_{1t}] \\ & + \frac{1}{2} \sum_{k} \rho_{k11} . [\log w_{ks} - \log w_{kt}].[\log T_{1s} - \log T_{1t}]^2\end{aligned} \qquad (3.10)$$

and equation (2.11) becomes

$$TFP_{s,t} = -\left[\frac{1}{2}(ECQ_s + ECQ_t - 2).\Delta\log Q^C\right.$$

$$+ \frac{1}{2}\sum_l (ECT_{ls} + ECT_{lt}) \cdot (\log T_{ls} - \log T_{lt}) \qquad (3.11)$$

$$\left. + \frac{1}{2}\sum_k \rho_{kll} \cdot (\log w_{ks} - \log w_{kt}) \cdot (\log T_{ls} - \log T_{lt})^2\right]$$

Finally, the condition required for the envelope inequalities in (3.1) to hold becomes

$$\phi_{ll} + \sum_k \rho_{kll} \log w_k > \tau_{ll} \qquad (3.12)$$

4. Empirical Results: Cost Function Estimation

The cost function was estimated using annual pooled three digit automobile production data from Canada (1961-80), United States (1961-80) and Japan (1968-80). A more detailed description of the data is contained in the Data Appendix.

Equations (2.12 + 3.7) and (2.13 + 3.8) were estimated, with constraints (2.14) and (3.6) imposed, using the Zellner iterative technique to obtain maximum likelihood estimates. Initial estimation results implied that the regularity conditions for the cost functions were not satisfied at a number of data points. The cost function was not concave for Canada (16 observations) and non-monotone in the technical change index (Canada (9 observations) and U.S. (4 observations)). The minimal parameter constraints necessary to ensure local regularity over the sample were imposed.[12] In the case of the concavity constraints, this implied different second order parameters $\delta_{11,c}$, $\delta_{33,c}$, $\delta_{12,c}$, $\delta_{13,c}$ and $\delta_{23,c}$ for Canada. Since the regularity constraints are not nested in the basic specification, no formal testing was undertaken. However, the imposition of the constraints led to only a moderate decline in the log-likelihood function (from 545.17 to 536.29).

One additional set of constraints was imposed on the parameters. As described in more detail in Fuss and Waverman (1985), the product mix variable (T_3) was computed as an index where typical weights are assigned to different classes of automobiles (sub-compact, compact, intermediate, etc.) and an average weight for actual production is computed. This variable fluctuated fairly tightly around 2500 for Japan and 3500 for Canada and U.S. Hence it almost served as a dichotomous dummy variable for Japan versus North America. From initial estimation results it became clear that second order parameters involving T_3 could not be estimated and were set to zero. This had the effect of constraining the cost-product mix elasticity to be a constant over time for each country, although the elasticity could differ among countries.

The imposition of the above parameter constraints is reflected in the parameter estimates presented in Table 1. Table 2 presents the corresponding summary statistics. Own factor price elasticities and elasticities of substitution are contained in Table 3. Table 4 presents cost, scale, and technological conditions elasticities. The numbers in Tables 3 and Tables 4 are calculated at each individual country's mean data point.

Using the parameter estimates found in Table 1, we verified that the inequality condition (3.12) required by the envelope theorem is satisfied at each data point in the sample. The importance of including the third order capacity utilization terms is readily evident from the empirical results. Each of the parameters ρ_{k11}, $k=1,2,3$ is statistically significant, and the ones relating to capital and labour substantially so. The signs of the parameters are the correct ones, indicating that as underutilized capacity is utilized more intensively, the cost share of capital declines and the cost shares of labour and materials increase.

Table 2 indicates that the model fits the data rather closely. The Durbin-Watson statistics are in the inconclusive region, so there is no obvious problem of serial correlation.[13] Table 3 shows that factor demand is inelastic.

Table 4 demonstrates that production in all three countries is subject to increasing returns to scale at the mean data point. Surprisingly, Canada has the lowest scale elasticity. The capacity utilization elasticity shows that costs increase proportionately less than actual output, (potential output held constant) so that there are short-run economies of fill. Any increase in research and development expenditures appears to have more of a cost-reducing impact in Japan than in Canada or the U.S., although since the elasticities vary with the data, this cannot be determined for certain from the mean elasticities.

The cost-product mix elasticities are very small. This is not surprising since the output variable has been claculated from value and price data so that it is denominated in "standard" units (see Fuss and Waverman (1985) for details concerning the construction). If the long-run marginal cost of producing a vehicle is proportional to category weights,[14] then the cost-product mix elasticity would be zero. If there are economies of scale (i.e., non-proportionality) in producing larger (heavier) automobiles then the elasticity would be negative.

5. Empirical Results: Rates of Growth of Cost, Productivity and their Decomposition

Tables 5-9 present the empirical results on cost and productivity which are the focus of this paper. Table 5 contains our analysis of actual unit production costs over the 1970-80 period. The actual percentage cost increase in a common currency (Canadian dollars) is contained in column 1. This figure is calculated as the average of the increases over three 8-year periods: 1970-78, 1971-79 and 1972-80. The three year averaging process was used in all calculations of growth rates to smooth out somewhat the year-to-year fluctuations. In Canadian dollars, unit costs increased by 85.6% in Canada, 117.6% in the U.S. and 116.7% in Japan. Relative to the U.S., Canada improved its competitive position by a substantial amount and Japan did so by a small amount. The pattern of cost increases in each country's own currency tells a dramatically different story. The Japanese cost increase is only 22.7%, compared with 90.3% for the U.S. and 85.6% for Canada. The difference in the results is due to a substantial appreciation of the Japanese yen and a smaller appreciation of the U.S. dollar, relative to the Canadian dollar. Table 11 contains the time path of the relevant exchange rates which had such a large impact on inter-country differences in cost growth rates.

Table 5 also contains the decomposition of the unit cost increases. The decomposition in Table 5 and subsequent tables is with respect to unit costs as measured in the country's own currency. The bottom half of the table presents the conventional "sources of growth" percentages obtained from ratios of logarithmic differences (using equation 3.10).

The top half of the table presents an unconventional accounting which is, for some purposes, more informative. The number 10.8 under the column "price of labour" in the first row of Table 5 has the following interpretation. If all variables affecting cost other than the price of labour were constant over time at the geometric average of their values in the years 1970, 71, 72, 78, 79 and 80, unit production cost in Canada would have increased by 10.8% because of the actual increases in the price of labour. Similarly, the number -9.3 under the column "technical change" in the first row of Table 5 implies that if all variables except the technical change variable T_2 had been constant, Canadian unit production cost would have fallen by 9.3% over the period. There is a blank under the column "Interaction" since when only one variable is allowed to differ between time periods, the interaction term is identically equal to zero. From the above description, it can be seen that what we have calculated in the upper half of Tables 5-9 is a set of discrete comparative statics results for variations in the exogenous variables affecting unit production costs and total factor productivity. For a similar comparative statics analysis see Diewert and Morrison (1985).

The major determinant of cost increases in all three countries has been increases in materials prices. Technical change has been the major source of cost reduction, especially in Japan.

As noted in the introduction, capacity utilization rates have varied considerably from year-to-year in the North American automobile industry. Utilization rates for the relevant years of our sample are presented in Table 11. For the U.S., capacity utilization has varied from a high of

0.95 in 1972 to a low of 0.58 in 1980. This variation accounts for 6.7% of the U.S. unit cost increase (from Table 5). In order to analyse cost increases on a long-run basis, we present in Table 6 the long-run equilibrium results, 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 decline. The slight increase in the Japanese rate is not due to capacity utilization effects, but rather to the replacement of actual cost with cost estimated from the econometric model. The negative estimation residual (Table 5) implies that the estimated cost increase exceeds the actual cost increase.

Table 7 presents the long-run equilibrium decomposition in a slightly different way. The components of total factor productivity (TFP) growth are aggregated (using equation 3.11) 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 minimal compared with North American producers.

Tables 8 and 9 examine changes in total factor productivity in the three countries over the averaged 8 year period. Actual TFP grew only 7.7% in Canada and 8.3% in the U.S. compared with a 43.1% increase in Japan. The substantial decline in capacity utilization in the North American automobile industry between the early 1970's and the late 1970's had a much more significant impact on TFP growth than on unit cost increases. When capacity utilization effects are removed (Table 9), TFP growth during the period increases to 11.3% in Canada and 13.4% in the U.S., substantially higher than actual TFP growth, but still dwarfed by the Japanese growth of 39.8%. The contributions of the various sources of TFP growth are very similar in the three countries: approximately 80% is due to technical change and 20% to scale economies.

Table 10 contains average annual rates of growth of unit cost and total factory productivity corresponding to the total period proportionate growth contained in Tables 5-9. Among the more interesting figures in Table 10 is the U.S. automobile industry's yearly rate of long-run productivity growth. A growth rate of 1.6% is high relative to the total manufacturing rate of less than 1%[15], but pales beside the Japanese auto industry's TFP growth rate of 4.3%. Similarly, while the Canadian rate of 1.4% is higher than average for manufacturing, it is well below the Japanese growth rate.

6. Conclusions

In this paper we have calculated and analysed the automobile industry's cost and productivity experience during the 1970's in Canada, 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 during the 1970's masked the superior performance of the Japanese auto industry relative to the North American industry during that period. Of course rates of growth analysis cannot determine whether Japan was just catching up to North American productivity levels or pulling ahead. A levels analysis is required to answer that important question. Our preliminary analysis of cost and productivity levels (Fuss and Waverman (1985)) suggests that the catch-up story is essentially correct, with the Japanese industry slightly more productive (1-2%) than the U.S. industry by 1980, at normal capacity utilization rates.

Finally, we have emphasized the importance of taking account of variations in capacity utilization when analysing TFP growth rates for an industry such as the automobile industry. Failure to do so would have led to a 31% underestimate of TFP growth in Canada during the 1970's and a 37% underestimate for the United States.

FOOTNOTES

1. We are also in the process of making level comparisons. See Fuss and Waverman (1985).
2. For a description of the Quadratic Lemma see Diewert (1976) and Denny and Fuss (1983). The specific decomposition formula (2.3) can be found in Denny and Fuss (1980) and Denny, May and Fuss (1981).
3. The empirical results specified below assume a single output technology and use a "product mix" characteristic variable to account for the effect of a different output composition on costs. Since a logical alternative specification (given sufficient data) is the multiple output cost function, we will provide the decomposition analysis for this case.
4. If the producer engages in marginal cost pricing and constant returns to scale exist, then $\Delta \log Q^C$ is just the change in the Tornqvist approximation to the Divisia aggregate index.
5. Of course neither quasi-fixed factors nor utilization rates are truly exogenous to the firm's decision process. What is meant by "exogenous" in this context is that the observed variables are not in long-run equilibrium; i.e., the levels of quasi-fixed factors are not necessarily chosen to equate the marginal rate of factor substitution to the current ratio of factor prices, and the rate of actual output flow is not necessarily equal to the designed (or normal) rate of flow.
6. See Miller (1985) for a discussion of the case of vehicle assembly.

7. The main disadvantage of the approach taken in this paper is that the only disequilibrium feature which can be captured is the deviation of actual from designed output. While this is by far the most important source of disequilibrium in the automobile industry, disequilibrium due to fluctuations in factor prices can be captured by the variable cost function model.

8. Detailed definitions of the variables and sources of data are contained in the Data Appendix

9. Let Q^N = designed (normal) output and Q^A = actual output in the short run. Then

$$ECT_1 = \frac{\partial \log C}{\partial \log T_1} \qquad \frac{\partial \log C}{\partial \log (Q^A/Q^N)\big|Q^N \text{ constant}}$$

$$= \frac{(Q^A/Q^N)}{C} \cdot \frac{\partial C}{\partial (Q^A/Q^N)\big|Q^N \text{ constant}}$$

$$= \frac{(Q^A/Q^N)}{C} \cdot Q^N \cdot \frac{\partial C}{\partial Q^A} = \frac{Q^A}{C} \cdot \frac{\partial C}{\partial Q^A}$$

$$= \frac{\partial \log C}{\partial \log Q^A}\bigg|Q^N \text{ constant}$$

10. For example, $\frac{\partial SRAC}{\partial Q} = \frac{\partial (C/Q^A)}{\partial Q^A} = \partial(C/\frac{Q^N}{Q^N})/\partial(\frac{Q^A}{Q^N})$

$$= \frac{\partial (C/T_1)}{\partial T_1}$$

$$= SRTC^{-1}[ECT_1 - 1]$$

11. The specification adopted is still not sufficiently flexible to deal with the case of overutilization of capacity since when

$T_1 > 1$, an increase in T_1 will lead to an increase in the cost share of capital, which is counterintuitive. This does not create a problem for the current application since only 6 of the 53 observations have $T_1 > 1$ and the maximum value of T_1 in the sample is 1.04. In cases where this problem is more significant, one possible solution is to replace the coefficients ρ_{k11} with $\rho_{k11}.SV$ where SV, a switch variable, equals +1 when $T_1 \leq 1$ and equals -1 when $T_1 > 1$.

12. The constraints were minimal in the sense that the concavity condition was satisfied over the complete sample with only one data point (Canada, 1974) being subject to a binding constraint. Similarly, the monotonicity conditions were satisfied with only two binding constraints (Canada, 1961 and U.S., 1961). To some extent this result was fortuitous since no formal inequality restrictions algorithm was attempted. For an example of the use of such a formal procedure, see Hazilla and Kopp (1985).

13. The inconclusive region is quite wide, given the large number of parameters and relatively small number of data points. A first order serial correlation adjustment was attempted but resulted in implausibly high estimates of scale elasticities, especially for Japan. This result suggests that the first order filtering process is a misspecification and thus the non-filtered results are presented.

14. This is a fact widely believed in the industry.

15. Compare estimates by Berndt and Fuss (1982) and Norsworthy and Malmqvist (1983) for example.

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 (1985). The general data sources were the Annual Surveys (or Census) of Manufacturers in each country. One problem with these data is the omission of a number of automotive-related production statistics from these annual surveys undertaken by the specific country's statistical office. Several relevant 4 digit SIC codes are not classified to the Motor Vehicles Industries in the USA and Canada (for example, automotive products foundries are classified to SIC 294 - foundries in Canada; in the USA, automotive stampings is included in All Metal Stampings prior to 1972). These omissions affect our results to the extent that some bias is imparted if the omitted sub-industries are significantly different from those included.

Nominal gross output data were taken from the central statistical surveys and converted to real output in constant dollars by applying the appropriate price deflators (available in Canada from Statistics Canada, in the USA, from the Bureau of Industrial Economics (B.I.E.) and in Japan from the Bank of Japan).

The output price deflators are indices which are normalized to be 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, except for very small differences in some factor price related second order terms, the estimated characterization of the production process in terms of elasticities is essentially invariant to the choice of the benchmark data set which is used to bridge the inter-country price indices to obtain absolute level comparisons. This is also true for country-specific rates of growth of cost and total factor productivity, which are the topics of this paper. However, the data are also being used to make inter-country 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 (1985). Of course the country-specific zero and first order regression coefficients contained in Table 1 do depend on the specific benchmark data set used to bridge the country-specific data.

Three inputs are used - materials, labour and capital. Materials price deflators were available for all three countries. The total compensation (rather than just the money wage) of labour has been calculated and hours worked estimated for production and non-production workers (except in Japan where the total number of workers has not been disaggregted). Real capital stock data were available for Canada (Garston, 1983) and the USA (Norsworthy and Malmquist (1983), Levy and Jondrow (1983)), but had to be estimated for Japan using data from the Annual Census and the perpetual inventory method.

The appropriate price of capital for our purposes is the ex ante user cost of capital services. Appropriate series at the 3 digit level were not available. For Canada we used a series for the 2 digit industry, transportation equipment, constructed by Michael Denny. The automotive industry-specific capital service price series which were avilable for the U.S. had been estimated by the residual method, which is an inappropriate ex ante measure for such a highly cyclical industry. We have instead utilized a user cost of capital series for U.S. total manufacturing (which would not be subject to such cyclical variations) presented in Norsworthy and Malmqvist (1983). This series is available only to 1977 and was updated to 1980 using internal U.S. Bureau of the Census capital service price data. The capital service price for Japan is an extrapolation of the series for Japanese total manufacturing also presented in Norsworthy and Malmqvist (1983). That series was available through 1978. Our extrapolation involved using the change in the Japanese prime interest rate beyond 1978 (DRI Japan Survey) and the changes in the price deflator for plant and equipment for the Japanese transportation equipment industry (Source: Price Indexes Annual).

Capacity utilization rates were calculated from data for vehicle assembly. We began by constructing a series for maximum output. Maximum (potential) output was measured in the USA and Canada as the maximum weekly nameplate output and in Japan as the maximum monthly output. Capacity utilization was initially measured as the ratio of actual production to maximum production. The "normal", or designed, capacity utilization rate was defined as the average utilization rate for Japan over the period 1969-80. Actual capacity utilization rates were normalized so that this average rate was equal to unity. Capacity (normal) output was defined as the actual output divided by the normalized capacity utilization rate.

We have estimated a technological change indicator - the ˋcapital stock' of Research and Development. This stock is constructed from annual R &D expenditures by converting them to a real capital stock utilizing the perpetual inventory method, the country-specific CPI and a depreciation rate of 15%. For Canada and the USA, we aggregated the two capital stocks into one series, assuming that the same technology was available to the producers in both countries. Our data on R & D expenditures for Japan began in 1966. Therefore, we needed a benchmark R & D stock. We assumed that in 1966 the technology available to Japan could be represented by the R & D stock per automobile produced in North America. We multiplied this value by the automobile production in Japan in 1966 to arrive at our benchmark. Since automobile production in Japan in 1966 was quite small relative to North America, the above procedure assigns a small value of the technical change index to Japan in 1966. Because of the way in which the R & D index was constructed, it has only a tentative link to the effect of R & D expenditures on costs. We believe it is more properly viewed as a method of tracking the country-specific unexplained technical change. From this point of view the variable is similar to a time trend and was utilzied because it consistently outperformed a time trend in the regression analysis.

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TABLE 1

Estimation Results

Parameter	Estimate	Standard Error
α_0	14.327	0.008
$\alpha_{0,US}$	-0.063	0.117
$\alpha_{0,J}$	0.212	0.168
α_1	0.091	0.002
α_2	0.782	0.002
α_3	0.127	0.002
$\alpha_{1,US}$	0.079	0.017
$\alpha_{2,US}$	-0.305	0.020
$\alpha_{3,US}$	0.227	0.016
$\alpha_{1,J}$	0.106	0.008
$\alpha_{2,J}$	-0.219	0.018
$\alpha_{3,J}$	0.113	0.015
β_1	0.957	0.044
$\beta_{1,US}$	-0.029	0.154
$\beta_{1,J}$	-0.149	0.102
θ_1	0.957	0.044
θ_2	0.216	0.072
θ_3	-0.091	0.065
$\theta_{1,US}$	-0.029	0.154
$\theta 2_{,US}$	-0.189	0.187
$\theta_{3,US}$	0.113	0.094
$\theta_{1,J}$	-0.149	0.102
$\theta_{2,J}$	0.033	0.149

$\theta_{3,J}$	0.069	0.319
δ_{11}	0.085	0.008
$\delta_{11,c}$	0.070	0*
δ_{22}	0.111	0.018
δ_{33}	0.053	0.011
$\delta_{33,c}$	0.061	0.018
μ_{11}	0.013	0.059
ϕ_{11}	0.970	0.184
ϕ_{22}	-0.429	0.072
δ_{12}	-0.071	0.008
$\delta_{12,c}$	-0.060	0*
δ_{13}	-0.014	0.005
$\delta_{13,c}$	-0.010	0*
δ_{23}	-0.040	0.013
$\delta_{23,c}$	-0.051	0.018
ϕ_{12}	0.065	0.065
λ_{11}	-0.012	0.008
λ_{21}	0.098	0.010
λ_{31}	-0.086	0.008
Λ_{11}	-0.012	0.008
Λ_{21}	0.098	0.010
Λ_{31}	-0.086	0.008
Λ_{12}	-0.032	0.013
Λ_{22}	-0.044	0.014
Λ_{32}	0.076	0.010
τ_{11}	0.013	0.059

τ_{12}	0.065	0.065
ρ_{111}	0.444	0.056
ρ_{211}	-0.123	0.060
ρ_{311}	-0.321	0.021

* constrained to be a constant due to the imposition of the concavity restrictions

TABLE 2

Summary Statistics

Equation	R^2	Durbin-Watson Statistic
cost	0.9998	1.33
capital share	0.9816	1.10
materials share	0.9830	1.00

TABLE 3a

Factor Own Price Elasticities

(computed at the mean data point)

Input	Canada	United States	Japan
Capital	-0.16	-0.33	-0.40
Materials	-0.09	-0.17	-0.17
Labour	-0.43	-0.53	-0.42

TABLE 3b

Elasticities of Substitution (Allen-Uzawa)

(computed at the mean data point)

Inputs	Canada	United States	Japan
Capital-Materials	0.17	0.35	0.52
Capital-Labour	0.22	0.58	0.47
Labour-Materials	0.53	0.67	0.48

TABLE 4

Cost-Output Elasticities, Scale Elasticities, Capacity Utilization Elasticities, Technical Change Elasticities, and Product Mix Elasticities

(computed at the mean data point)

Elasticity	Canada	United States	Japan
Cost-Output	0.96	0.93	0.92
Scale	1.04	1.07	1.09
Cost-Capacity Utilization	0.79	0.82	0.92
Cost-Technical Change	-0.21	-0.24	-0.35
Cost-Product Mix	-0.09	0.02	-0.02

Table 5

Unit Production Cost Increase (1978-80 versus 1970-72)

Country	Unit Production Cost Increase (%)			Sources of Increase								
	Canadian Dollars	U.S. Dollars	Yen	Price of Labour	Price of Capital	Price of Materials	Product Mix	Scale Economies	Technical Change	Capacity Utilization	Interaction	Estimation Residual
Canada	85.6			10.8	7.0	68.5	-0.3	-2.3	-9.3	3.4	—	0.6
U.S.	117.6	90.3		17.5	12.5	55.9	-0.3	-2.4	-11.1	4.2	—	0.6
Japan	116.7		22.7	13.9	3.4	49.1	-0.2	-7.2	-30.2	-0.2	—	-2.2
				Percentage Contributions to Increase								
Canada	85.6			16.6	11.0	84.4	-0.6	-3.6	-14.3	5.6	-0.0	1.0
U.S.	117.6	90.3		25.1	18.3	69.0	-0.4	-3.6	-16.3	6.7	-0.2	1.0
Japan	116.7		22.7	63.6	16.4	195.1	-1.0	-33.8	-128.7	-0.8	0.0	-10.8

Table 6

Unit Production Cost Increase (1978-80 versus 1970-72)
(Long-Run Equilibrium)

Country	Unit Production Cost Increase (%)			Sources of Increase					
	Canadian Dollars	U.S. Dollars	Yen	Price of Labour	Price of Capital	Price of Materials	Product Mix	Scale Economies	Technical Change
Canada	79.1			10.0	5.4	71.9	-0.3	-2.1	-8.7
U.S.	107.7	81.7		16.9	10.7	59.2	-0.3	-2.3	-10.6
Japan	121.9		25.7	14.0	3.4	49.1	-0.2	-7.2	-30.2
				Percentage Contributions to Increase					
Canada	79.1			16.3	9.1	93.0	-0.6	-3.5	-14.3
U.S.	107.7	81.7		26.2	17.0	77.9	-0.5	-3.8	-16.9
Japan	121.9		25.7	57.1	14.7	174.7	-0.9	-30.3	-115.3

Table 7

Unit Production Cost Increase (1978-80 versus 1970-72) (Long-Run Equilibrium)

Country	Unit Production Cost Increase (%)			Sources of Increase			
	Canadian Dollars	U.S. Dollars	Yen	Price of Labour	Price of Capital	Price of Materials	TFP Growth
Canada	79.1			10.0	5.4	71.9	-11.3
U.S.		81.7		16.9	10.7	59.2	-13.4
Japan			25.7	14.0	3.4	49.1	-39.8

				Percentage Contributions to Increase			
Canada	79.1			16.3	9.1	93.0	-18.4
U.S.		81.7		26.2	17.0	77.9	-21.2
Japan			25.7	57.1	14.7	174.7	-146.5

Table 8

Total Factor Productivity Growth (1978-1980 versus 1970-1972)

Country	Total Factor Productivity Growth (%)	Sources of Growth					
		Product Mix	Scale Economies	Capacity Utilization	Technical Change	Interaction	Estimation Residual
Canada	7.7	0.3	2.3	-3.4	9.3	—	-0.6
U.S.	8.3	0.2	2.4	-4.2	11.1	—	-0.6
Japan	43.1	0.2	7.2	0.2	30.2	—	2.2

		Percentage Contributions to Growth					
Canada	7.7	4.7	30.3	-46.9	120.0	0.0	-8.2
U.S.	8.3	2.2	28.4	-54.1	131.2	1.1	-8.1
Japan	43.1	0.5	19.3	0.5	73.5	0.0	6.2

Table 9

Total Factor Productivity Growth (1978-80 versus 1970-72) (Long-Run Equilibrium)

Country	Total Factor Productivity Growth (%)	Sources of Growth		
		Product Mix	Scale Economies	Technical Change
Canada	11.3	0.3	2.1	8.7
U.S.	13.4	0.3	2.3	10.6
Japan	39.8	0.2	7.2	30.2

		Percentage Contributions to Growth		
Canada	11.3	3.2	19.0	77.8
U.S.	13.4	2.2	17.7	80.1
Japan	39.8	0.6	20.7	78.7

Table 10

Average Yearly Rates of Increase
1970-72 versus 1978-80

Country	Rates of Increase (%)							
	Unit Production Cost						Total Factor Productivity	
	Actual			Long-Run Equilibrium			Actual	Long-Run Equilibrium
	Canadian Dollars	U.S. Dollars	Yen	Canadian Dollars	U.S. Dollars	Yen		
Canada	8.0			7.6			0.9	1.4
U.S.	10.2	8.4		9.6	7.8		1.0	1.6
Japan	10.2		2.6	10.5		2.9	4.6	4.3

Table 11

Exchange Rates and Capacity Utilization Rates

Year	Exchange Rates		Capacity Utilization Rates		
	U.S. ($U.S./$CAN.)	Japan (YEN/$CAN.)	Canada	U.S.	Japan
1970	0.96	343	0.75	0.74	0.99
1971	0.99	344	0.84	0.93	1.00
1972	1.01	306	0.88	0.95	0.99
1978	0.88	182	0.86	0.95	1.02
1979	0.85	186	0.76	0.83	1.00
1980	0.86	193	0.62	0.58	1.02