R&D Investment and Productivity Growth

in U.S. and Canadian Food Manufacturing

Connie Chan-Kang and Steven Buccola

Connie Chan-Kang is a senior research assistant in the International Food Policy Research Institute, Washington, D.C. She earned her M.S. degree from Oregon State University and B.S. degree from Université Laval. Steven Buccola is a professor in the Department of Agricultural and Resource Economics, Oregon State University.

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Gradual reductions in Canada-U.S trade barriers are likely to intensify competition between Canadian and U.S. food manufacturers. The key to predicting the long-run implications of such liberalization is to understand changes in relative productive efficiency in the two countries. In the present paper we examine relative productivity growth in Canadian and U.S. food manufacturing, emphasizing the effects of R&D effort and capacity utilization.

Productivity growth can come about from technical change, from output growth in the presence of scale economies, from adjustments in quasi-fixed inputs, and from changes in the competitiveness of firms' pricing behavior (Morrison 1992). Most econometric studies seek to decompose productivity growth into two or more of these elements. Here we assume zero scale economies — constant returns to scale — in the long run, when the quasi-fixed capital stock has adjusted to its long-run optimum. However, we allow capital stock to remain fixed in the short run, so that capital adjustments affect productivity growth. Our principal objective is to compare the Canadian and U.S. food sectors with regard to two questions: (i) production cost and (iii) rate of productivity growth, expressed in terms of both cost and output.

Cost Model

Our approach was to estimate, for each country, an aggregate short-run food processing cost function, an input demand function, and an output supply function. Inputs were divided into labor, capital, and materials. Labor included custom services as well as hired management and workers. Materials included raw farm goods, packaging, and energy.
We expressed conventional capital stock and the stock of R&D capital as a percent of output,

so that the short-run cost function was specified for each country in translog form as

$$
\begin{aligned}
(1)\qquad \ln G \;=\; & \alpha_o + \alpha_w \ln W + \alpha_y \ln Y + \alpha_k \ln(K/Y) + \alpha_r \ln(R/Y) + \\
& 0.5\,[\beta_{ww} \ln^2 W + \beta_{yy} \ln^2 Y + \beta_{kk} \ln^2(K/Y) + \beta_{rr} \ln^2(R/Y)] + \\
& \gamma_{wy} \ln W \ln Y + \gamma_{wk} \ln W \ln(K/Y) + \gamma_{wr} \ln W \ln(R/Y) + \\
& \gamma_{yk} \ln Y \ln(K/Y) + \gamma_{yr} \ln Y \ln(R/Y) + \gamma_{kr} \ln(K/Y) \ln(R/Y) + \ln W_m
\end{aligned}
$$

where G is cost of labor, materials, services, and energy; $W = W_\ell / W_m$ is the index of labor wages divided by index of material prices; Y is the index of output quantity; K is the index of conventional capital stock; and R is R&D capital stock. Labor and material prices are expressed in ratio form to maintain linear homogeneity in input prices. In all estimates, short-run cost was concave in input prices at sample mean.

Log differentiating (1) with respect to labor wage W_ℓ gives the labor share (S_ℓ) equation, and with respect to output gives the revenue share (PY/G) equation, where P is the index of wholesale prices (1992 = 100) and is (PY/G) revenue as percent of noncapital cost. The latter equations were estimated jointly with (1).

Long-run constant returns to scale are maintained by ensuring that $\partial \ln G/\partial \ln Y + \partial \ln G/\partial \ln K = 1$ at all sample points (Lau). In the context of (1), this implies restrictions

$$(2)\qquad \alpha_y = 1 + \alpha_r \qquad \gamma_{wy} = \gamma_{wr} \qquad \beta_{yy} = \beta_{rr} = \gamma_{yr} \qquad \gamma_{yk} = \gamma_{kr}\,.$$

Although one wouldn't expect individual food industries to operate always at long-run constant returns, it is a reasonable assumption for the food manufacturing sector as a whole. Bhuyan and Lopez recently confirmed this assumption for the U.S. at the SIC 2-digit level.

Productivity Comparison Measures

In a short-run context, the rate of return to R&D capital can be estimated by successively differentiating the Canadian and U.S. versions of (1) with respect to R&D capital; evaluating results at the respective country's own price, output, and capital levels; and computing the difference:

$$(3) \qquad \partial G_{\text{can}}/\partial R_{\text{can}}\ (W_{can}, Y_{can}, K_{can}, R_{can}) \ - \ \partial G_{\text{us}}/\partial R_{\text{us}}\ (W_{us}, Y_{us}, K_{us}, R_{us}).$$

Relative production cost in the two countries is a meaningful concept only if we compare Canadian with U.S. costs in a situation in which the two countries are assumed to produce the same output and face the same capital stock, R&D stock, and input prices:

$$(4) \qquad GAP_{\text{c}}^{\text{f}} \ = \ \ln G_{\text{can}}\,(W^{\circ}, Y^{\circ}, K^{\circ}, R^{\circ}) \ - \ \ln G_{\text{us}}\,(W^{\circ}, Y^{\circ}, K^{\circ}, R^{\circ})$$

where $GAP_{\text{c}}^{\text{f}}$ is the short-run (quasi-fixed-capital) cost gap and $W^{\circ}, Y^{\circ}, K^{\circ}, R^{\circ}$ are, for example, midpoints between Canadian and U.S. sample values. Under these assumptions and constant returns to scale, $GAP_{\text{c}}^{\text{f}}$ reflects the inter-country difference in variable factor productivity plus any inter-country difference in the extent to which the quasi-fixed capital stock departs from its long-run optimal level (Jorgenson and Nishimizu).

To estimate primal and dual rates of productivity growth, we turn to Morrison's (1992) model of dual productivity change in the presence of quasi-fixed inputs. If capital is fixed in the short run, the proportionate rate of change of total cost *C*, holding input prices and output fixed, can be decomposed as

$$(5) \qquad \epsilon_{\text{ct}}^{\text{f}} \ = \ -\,\epsilon_{\text{yt}}^{\text{f}} \cdot \epsilon_{\text{cy}} \cdot (1 - \epsilon_{\text{ck}})$$

where $\epsilon_{\text{yt}}^{\text{f}}$ is the percentage rate of change of output, holding conventional inputs fixed; ϵ_{cy} is total cost elasticity $\partial \ln C/\partial \ln Y$; and $\epsilon_{\text{ck}} = \partial \ln C/\partial \ln K$ is the percentage rate of change of total cost with respect to capital stock. When capital has adjusted fully, $\epsilon_{\text{ck}} = 0$ and we are left with the usual decomposition of dual productivity growth rate $\epsilon_{\text{ct}}^{\text{f}}$ into primal rate $\epsilon_{\text{yt}}^{\text{f}}$ and cost elasticity

ϵ_{cy} (Ohta). Assuming long-run constant returns as in the present study, $\epsilon_{cy} = 1$.

Berndt and Fuss, and Morrison (1992), have shown that $(1 - \epsilon_{ck})$ in (5) is a convenient indicator of capacity utilization, expressible as

$$CU = 1 - \epsilon_{ck} = (G + Z_k K) / (G + W_k K), \tag{6}$$

in which $Z_k = - \partial G/\partial K$ is the shadow price and W_k the market price of capital. Capital stock minimizes total cost when $Z_k = W_k$; there, CU equals unity, so $\epsilon_{ct} = - \epsilon_{yt}$ under long-run constant returns.

Canadian data were expressed relative to a U.S. base year through Purchasing Power Parity indexes, which we constructed from published and private sources. Reported R&D expenditures from Statistics Canada and the National Science Foundation were used in conjunction with the perpetual inventory method to construct time series of R&D knowledge stocks in each country. All prices and costs are expressed in constant 1992 U.S. dollars. The final sample ranged from 1962 to 1992 in Canada and from 1962 to 1993 in the United States. Explanatory variables were divided by their sample means prior to regression.

Comparative Growth and Cost Gap

To summarize relative factor price changes in the two countries, real wage rates in Canada have averaged well below, but real material prices well above, those in the United States. Both the inter-country wage rate differential and the inter-country material price differential have remained fairly constant since 1963. Real wages in both countries have trended upward, while real material prices have cycled around a roughly flat trend line. Although real capital prices in the Canada have averaged lower than in the U.S., they have stayed equal to or above U.S. prices since the early 1980s.

Cost function estimates are given in tables 1 and 2. The negative and significant signs on α_r imply R&D investment has significantly reduced noncapital costs in both countries. A 10% increase in R&D capital has been associated in Canada with a 0.92% reduction, and in the U.S. with a 2.22% reduction, in noncapital cost. The negative signs on γ_{wr} indicate that, at sample means, R&D effort has been labor-saving and material-using, although less so in Canada than in the U.S. By restriction $\gamma_{wr} = \gamma_{wy}$ in (2), therefore, output growth has been labor-saving and material-using as well. Morrison (1997) found a similar labor-saving bias in food manufacturing technical change. The negative sign on γ_{wk} in the Canadian model implies that conventional capital investment in Canada also has been labor-saving and material-using.

As Miner and others have observed, R&D investment rates in the U.S. food sector have been higher than in Canada. For example, R&D-to-output ratio *R/Y* averaged 9.61 in the U.S. sample and only 5.85 in the Canadian sample. Higher R&D investment rates suggest that food manufacturing productivity might be higher in the U.S. as well. This is confirmed by computing short-run cost gap (6), namely the noncapital cost difference one would observe between the two countries if both faced the same factor prices and produced the same output with the same capital stock. At the grand sample mean, the cost gap was 0.22: noncapital costs in Canada would be 22% higher than in the U.S. if each country moved halfway toward the other's factor prices, output, and capital stock. Inasmuch as capital expenditures would then be the same in the two countries, and capital represents close to 10% of total cost in each country, the corresponding total short-run cost gap would be about 20% in favor of the U.S.

Growth in the Long Run and the Short Run

We can employ the results in tables 1 and 2 to characterize the standard primal and dual rates of productivity growth in both the short run and long run. For each country, we first computed the time series of capital's shadow prices $Z_k = -\partial G/\partial K$. We used these as the prices of capital to compute: (i) short-run (quasi-fixed-capital) primal productivity growth rates $\epsilon_{yt}^f = d\ln Y/dt - \Sigma_i S_i \partial \ln X_i/\partial t$, where S_i and X_i are, respectively, expenditure share and quantity of the i^{th} input (K, L, M); (ii) dual rates of productivity growth ϵ_{ct}^f, allowing for short-run capital fixity as specified in (5). We found that capital's shadow prices in Canada generally have stayed below the corresponding market prices, implying the Canadian food sector has operated somewhat below capacity. However, deviations between shadow and market prices have been small, implying that capacity under-utilization has detracted little from Canadian food manufacturing efficiency. Rao and Lempriere (p. 29) argued in the same vein that capacity utilization contributed little to the 1980s slowdown in Canadian manufacturing productivity. By contrast, shadow prices in the U.S. have stayed above market prices, implying that conventional capital in the U.S. has been used too intensively.

Capacity utilization differences seem to have affected relative productivity growth. Table 3 gives the short-run primal (ϵ_{yt}^f) and dual (ϵ_{ct}^f) productivity growth rates computed under the assumption of capital quasi-fixity. Included in table 3 are primal growth rates ϵ_{yt} computed under the assumption that capital is valued at market prices. Accounting for capital quasi-fixity does little to alter the overall patterns of productivity change during the 1963 - 1992 period. In terms of decade averages, the primal measure of productivity growth in Canada has fallen continuously since the end of the 1960s. Growth in the U.S. slumped badly (indeed averaged close to zero) during the stagflation of the 1970s but rebounded sharply in the 1980s.

Cumulating the ϵ_{ct}^f and ϵ_{yt}^f values in table 3 to form indexes of comparative productivity levels provides another view of Canadian and U.S. performance. Figure 1 does so with the two countries' dual growth rates ϵ_{ct}^{f}. Each line in figure 1 reflects the level of noncapital cost as time (and thus productivity change) proceeds but output, capital stock, and input prices remain fixed. The lines reflect comparative totals in the sense that Canadian and U.S. costs are assumed equal to one another in a base year (here 1962). Figure 1 makes clear that the cumulative cost-reducing effect of Canadian productivity growth flattened out in the mid-1970s and has been negligible since then. By contrast, productivity-induced cost reductions in the U.S. have continued strongly into the 1990s, interrupted only by the mid-1970s oil crisis. The implications of these trends for Canada's share of the North American food market are substantial.

Conclusions

Canadian productivity growth has lagged dramatically behind U.S. growth in recent decades. Indeed, in terms of decade averages, productivity growth in Canada has fallen continuously since the late-1960s, and cost-reducing technical change appears to have all but ceased since the mid-1970s. In contrast, U.S. productivity rebounded sharply after the 1970s slowdown and has continued to improve. The most likely explanation for the widening technology gap is Canadian manufacturers' failure to participate fully in the extensive cost-cutting and merger moves begun by U.S. firms in the early 1980s. The substantial shortfall in Canadian R&D expenditures per unit output is but one sign of this general underinvestment in technical change. Because rates of return to R&D capital — public and private — are high, a shortfall in R&D investment has serious repercussions on productivity and cost. At 1962 - 1993 grand sample means, the subequilibrium cost gap between Canada and the U.S. was 22% in favor of the United States.

Capacity utilization has played a role in productivity growth, especially in the U.S., where there is some evidence of over-intensive use of capital. For example, the cost of capital disequilibrium appears to have detracted modestly from the rate of productivity-induced cost reduction, more so in the U.S. than in Canada. Overall, however, we find evidence to support the contention that excessive federal and provincial regulation, and underinvestment in research and development, have diminished the competitiveness of the Canadian food industry *vis a vis* the United States (Miner, p. 237).

The labor-saving, material-using nature of food manufacturing technical change likely has been a response to pronounced secular increases in labor/material price ratios during the past three decades. Unfortunately, material-using technical improvements put Canadian food manufacturers at a disadvantage relative to their U.S. competitors, because material (farm product and packaging) prices remain substantially higher in Canada than in the United States. Technological innovations which Canadian firms adapt from abroad often fail to take advantage of Canada's relatively low manufacturing wage rates, and instead make intensive use of Canada's chief liability, its material costs. Correcting this imbalance will require that Canada reduce raw product and packaging costs or develop food processing innovations suitable to its material-scarce factor endowments.

Table 1. Short-Run Cost Function, Canadian Food Manufacturing, 1962 - 1992.[a]

Parameter	*Variable*	*Estimate*	*Standard Error*
α_o		3.314	0.003
α_w	$\ln W$	0.311	0.003
α_y	$\ln Y$	0.908	0.014
α_k	$\ln(K/Y)$	-0.100	0.003
α_r	$\ln(R/Y)$	-0.092	0.014
β_{ww}	$\ln^2 W$	0.166	0.034
β_{yy}	$\ln^2 Y$	0.047	0.041
β_{kk}	$\ln^2(K/Y)$	-0.032	0.109
β_{rr}	$\ln^2(R/Y)$	0.047	0.041
γ_{wy}	$\ln W \ln Y$	-0.062	0.015
γ_{wk}	$\ln W \ln(K/Y)$	-0.104	0.034
γ_{wr}	$\ln W \ln(R/Y)$	-0.062	0.015
γ_{yk}	$\ln Y \ln(K/Y)$	0.031	0.021
γ_{yr}	$\ln Y \ln(R/Y)$	0.047	0.041
γ_{kr}	$\ln(K/Y) \ln(R/Y)$	0.031	0.021

[a] R^2s were as follows (listed by equation number in text): Equation (1): 0.997. Equation (2): 0.678. Equation (3): 0.806.

Table 2. Short-Run Cost Function, U.S. Food Manufacturing, 1962 - 1993.[a]

Parameter	*Variable*	*Estimate*	*Standard Error*
α_o		5.516	0.023
α_w	$\ln W$	0.265	0.006
α_y	$\ln Y$	0.778	0.039
α_k	$\ln(K/Y)$	-0.341	0.006
α_r	$\ln(R/Y)$	-0.222	0.039
β_{ww}	$\ln^2 W$	0.153	0.120
β_{yy}	$\ln^2 Y$	0.466	0.564
β_{kk}	$\ln^2(K/Y)$	-0.155	0.272
β_{rr}	$\ln^2(R/Y)$	0.466	0.564
γ_{wy}	$\ln W \ln Y$	-0.081	0.068
γ_{wk}	$\ln W \ln(K/Y)$	0.018	0.118
γ_{wr}	$\ln W \ln(R/Y)$	-0.081	0.068
γ_{yk}	$\ln Y \ln(K/Y)$	-0.003	0.069
γ_{yr}	$\ln Y \ln(R/Y)$	0.466	0.564
γ_{kr}	$\ln(K/Y) \ln(R/Y)$	-0.003	0.069

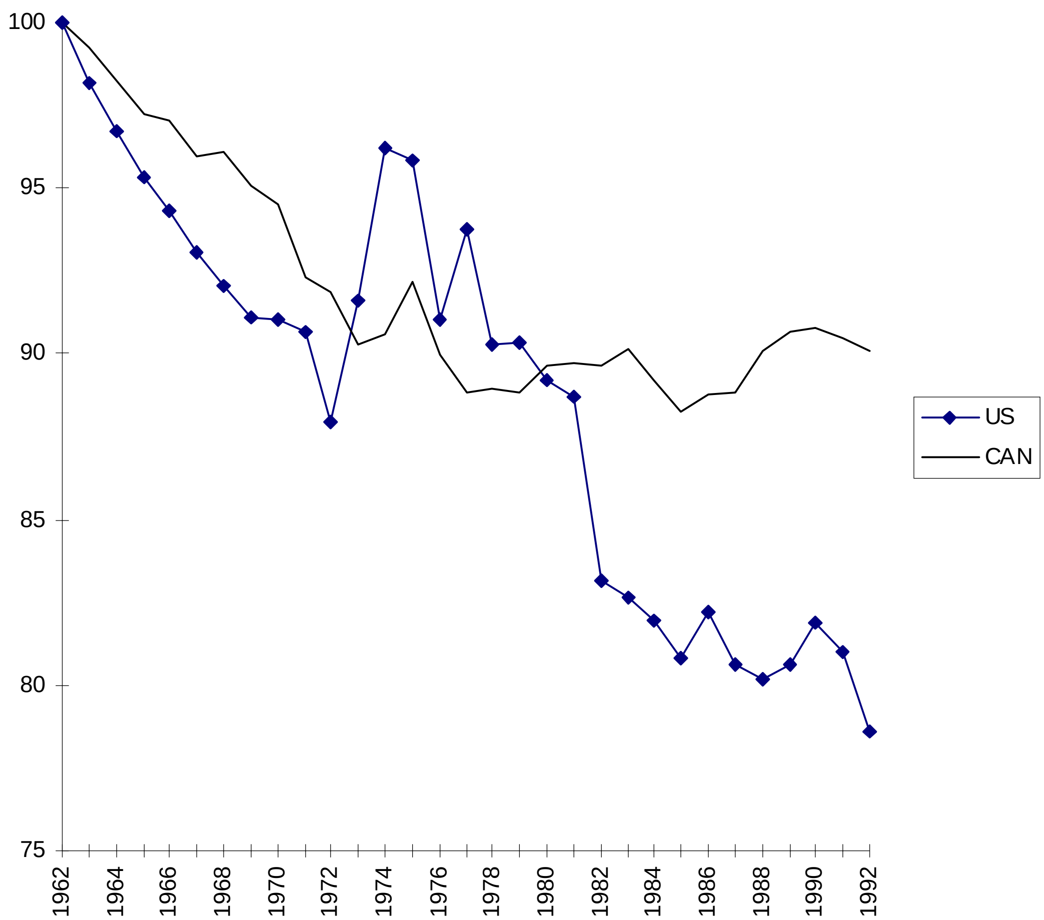
[a] R^2s were as follows (listed by equation number in text): Equation (1): 0.973. Equation (2): 0.524. Equation (3): 0.039.

Table 3. Comparative productivity growth rates, Canada and United States, 1963-1992.

	Canada			United States		
Year	ϵ_{yt}^{f}	ϵ_{ct}^{f}	ϵ_{yt}	ϵ_{yt}^{f}	ϵ_{ct}^{f}	ϵ_{yt}
1963	0.78	-0.76	0.77	1.50	-1.83	1.66
1964	1.02	-0.99	1.10	1.19	-1.45	0.92
1965	1.04	-1.00	1.04	1.16	-1.42	1.19
1966	0.20	-0.19	0.22	0.81	-0.99	1.08
1967	1.17	-1.13	1.12	1.04	-1.27	1.05
1968	-0.17	0.16	-0.24	0.83	-1.01	1.08
1969	1.02	-1.00	0.94	0.75	-0.91	1.09
1970	0.61	-0.59	0.56	0.08	-0.10	0.11
1971	2.29	-2.22	2.20	0.27	-0.33	0.41
1972	0.41	-0.40	0.43	2.21	-2.74	2.82
1973	1.69	-1.62	1.73	-2.88	3.65	-2.25
1974	-0.32	0.31	-0.26	-3.63	4.61	-4.72
1975	-1.63	1.58	-1.64	0.29	-0.35	1.08
1976	2.24	-2.17	2.40	3.93	-4.85	4.01
1977	1.16	-1.13	1.27	-2.22	2.75	-1.96
1978	-0.14	0.13	-0.12	2.79	-3.49	3.01
1979	0.15	-0.15	0.19	-0.08	0.10	0.64
1980	-0.85	0.84	-0.86	0.92	-1.16	1.31
1981	-0.06	0.06	-0.14	0.43	-0.53	0.39
1982	0.07	-0.07	0.04	4.54	-5.56	5.60
1983	-0.53	0.51	-0.55	0.38	-0.46	0.61
1984	0.99	-0.96	1.00	0.60	-0.73	0.50
1985	0.98	-0.94	1.01	0.95	-1.14	0.89
1986	-0.53	0.51	-0.54	-1.18	1.42	-1.22
1987	-0.02	0.02	0.08	1.36	-1.62	1.81
1988	-1.35	1.29	-1.43	0.35	-0.42	0.29
1989	-0.56	0.54	-0.73	-0.37	0.45	-0.48
1990	-0.15	0.14	-0.37	-1.06	1.25	-0.78
1991	0.31	-0.29	0.08	0.71	-0.84	1.13
1992	0.41	-0.38	0.40	2.04	-2.40	2.97
1963-72[a]	0.83	0.81	0.82	0.98	1.21	1.14
1973-81[a]	0.25	0.24	0.29	-0.05	-0.08	0.17
1982-92[a]	-0.03	-0.03	-0.09	0.76	0.91	1.03
1963-92[a]	0.34	0.33	0.32	0.59	0.71	0.81

[a] Simple averages of annual rates.

Figure 1. Cumulative cost reduction given fixed output, capital stock, and factor prices, Canadian and U.S. Food Manufacturing, 1962-1992.[a]



[a] 1962 = 100

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