AN ABSTRACT OF THE THESIS OF

Connie Chan-Kang for the degree of Master of Science in Agricultural and Resource Economics presented on October 21st, 1997. Title: R&D Investment and Productivity in the U.S. and Canadian Food Processing Sectors.

Redacted for Privacy

Abstract approved: ______________________________
Steven T. Buccola

Increased competition brought about by trade liberalization has raised the stakes for improving productivity in U.S. and Canadian food processing. A key element of productivity growth is technological change, which in turn results from R&D investment. The present study employs an econometric model to assess rates of technological change and productivity growth in the U.S. and Canadian food processing sectors, allowing for capital fixity in the short run.

Results suggest that the rate of technological change associated with R&D expenditure grew quickly in the U.S. and Canada from the early 1960's to early 1970s, followed by a slowdown during the mid- to late-1970s. The 1973 recession had a relatively severe negative impact on technological change in the U.S. food sector, while the early 1980's recession had a greater negative impact in Canada. The annual rate of technologically induced cost reduction averaged 8.04% in the U.S., and 1.04% in Canada, between 1983 and 1988. After 1988, however, the rate of technological change declined in the U.S. while it increased in Canada. In both countries, technological change is the main source of productivity growth. Rates of return to R&D expenditure are greater in the Canadian than in the U.S. food processing sector.

R&D Investment and Productivity in the U.S. and Canadian Food Processing Sectors

by

Connie Chan-Kang

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented October 21st, 1997
Commencement June 1998

Master of Science thesis of Connie Chan-Kang presented on October 21st, 1997

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Connie Chan-Kang, Author

ACKNOWLEDGEMENT

It is with real pleasure that I acknowledge a number of persons without whom the accomplishment of this thesis would not have been possible.

I am indebted to my major professor, Steven Buccola, for his guidance, encouragement, and patience during the past year while he was involved in the preparation of this thesis. I thank Joe Kerkvliet for his support, valuable comments, and suggestions. I also thank Jim Cornelius and Susan Hanna for their support.

The financial support for this thesis was provided by the National Research Initiative Competitive Grants Program, Agreement No. 96-35400-3619, U.S. Department of Agriculture.

To Jean-Pierre Maynard of Statistics Canada and William Gullickson of the Bureau of Labor Statistics I express my appreciation for data support.

Friends have played a vital part in carrying this thesis into fruition. I am grateful to Nancy Bergeron, Cathy Fock-Tave, Solange Nadeau and Shirley Joe for their help and encouragement. A special thanks to Ellen, Liane, and Ieda, lifetime members of the Burritos Club!

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R&D Investment and Productivity in the U.S. and Canadian Food Processing Sectors

Chapter 1: Introduction

In both the United States and Canada, food processing is a main contributor to the overall manufacturing sector in terms of value of shipment and source of employment. Indeed in 1994, food and beverages were respectively the second and third largest manufacturing sectors in the U.S. and Canada in terms of shipments value. Furthermore, food processors generate income to the agricultural sector as a main buyer for raw materials, and are closely linked to the distribution sector as an important supplier of commodities. Therefore, the performance of the food sector has a spillover effect to the overall economy.

The U.S. and Canadian food sectors are closely linked to each other, through geographic boundary and their trade relations, among other factors. After Japan, Canada is the United States main destination for food manufactured products, while the U.S. is Canada's most important trading partner.

In 1992, the North American Free Trade Agreement (NAFTA) was concluded between the U.S., Canada and Mexico. Increasing competition and the reduction of trade barriers puts pressure on food processors to maintain their share in domestic markets and to take advantage of new markets. A key to competitiveness is a food sector's ability to improve and maintain a high level of productivity. Productivity growth is the combined effect of improvements in technology and in the changes that increase the ratio of outputs to aggregate inputs. Productivity growth, in turn, lowers the cost of production at given input prices.

Keeping these considerations in mind, it is important to: (i) assess the U.S. food sector's competitive position relative to that of its second-largest trading partner, Canada; (ii) measure inter-country productivity differences and ascertain whether they are due to differences in scale economies, capacity utilization, or rates of technological progress.

Despite the economic importance of food processing and the stakes raised by NAFTA, little attention has been paid to analyzing productivity in the food processing sector. Furthermore, to my knowledge, no study has been conducted to assess the relative competitive position of the U.S. and Canadian food sectors, using an explicitly comparative econometric model. Single-country productivity studies do exist, in which productivity in the food sector has been estimated as part of manufacturing sector-wide investigation. Inter-country differences in productivity have also been estimated for the food sector, using the U.S. as a benchmark at a specific point in time. However, cross-study inconsistency in methodological approaches renders comparisons difficult (Hazeldine, 1991).

Typically, productivity studies in the food sector have been conducted under a long-run equilibrium framework. Long-run equilibrium assumes that all factors adjust instantaneously to exogenous shocks. As a consequence, factors of production are assumed to be employed at their optimal level and firms assumed to operate at full capacity at each point of time. Full equilibrium of all factors of production is, however, a restrictive assumption. In fact, in the short-run, fixity of some inputs precludes firms from using all inputs at their equilibrium levels. This in turn affects productivity measurement. Fuss and Waverman (1990), for instance, found that failing to take capacity utilization into account overstated long-run productivity growth in the U.S. automobile industry by 22%.

To address these limitations, the main objective of the present study is to assess productivity growth in the U.S. and Canadian food sectors, with special reference to capacity utilization and to research and development expenditures. Specifically, I propose to:

1. estimate and compare rates of productivity growth and technological change in the U.S. and Canadian food industries;
2. analyze the sources of productivity differentials between the U.S. and Canada, with special attention to technological change and to capital adjustment;
3. estimate long-run rates of productivity growth and decompose these rates into their sources;
4. draw policy implications.

To achieve these goals, I first present a profile of the U.S. and Canadian food processing sectors. Next, I review the theoretical approach I will employ to measure productivity, discuss the data set, and lay out the econometric model. In the last chapter, I present and analyze the empirical results.

Chapter 2: Profile of the U.S. and Canadian Food Processing Sectors

Food processing is among the leading sectors in U.S. and Canadian manufacturing in terms of income, employment, and output value. In order to understand the environment within which the food processing sector has evolved in each country, I discuss the characteristics of each sector below, with particular attention to size and structure. In the second part of the chapter, I describe the evolution of U.S. and Canadian food shipment value since 1962. Third, scale and degree of concentration of U.S. and Canadian food manufacturing sector are presented. Finally, I overview several studies that have attempted to measure the productivity of the food sector in either country.

2.1 Characteristics of the U.S. and Canadian Food Processing Sectors

After transportation equipment, the food and kindred products sector is the second largest manufacturing sector in the United States. In 1994, it contributed 1.4% of the U.S. GDP and 13% of total manufacturing shipment value, providing employment to over 1.5 millions of workers (Industrial Outlook 1994, Bureau of Census). In Canada, food and beverage processing is the third largest manufacturing sector, after transportation equipment and electronic products. In 1994, food and beverages accounted for 2.2% of the Canadian GDP and 13% of the total manufacturing shipment value, employing over 215,000 of workers (Statistics Canada, 1994; Agriculture Canada 1997).

The U.S. and Canadian food and beverage sectors share several similarities with one another. First, a closer look at the industries constituting this sector reveals that, in both countries, the top three industries in terms of value are meat and poultry, beverages, and dairy products. These three industries accounted for over half of the value of shipments in the U.S. and Canada in 1994. Second, the disaggregation of total costs into labor, capital, energy, material, and service components shows that food manufacturing is an intensive user of materials (raw farm products and packaging) and of capital, and to a lesser extent labor. In 1992, materials accounted for 59% of total food manufacturing cost in the U.S., followed by labor with 18% and capital with 13% (BLS, 1995). In Canada during that year, materials accounted for 51% of total cost, followed by capital and labor with 18% and 17%, respectively. Services accounted for 9% of total costs in the U.S. and 13% in Canada, while the share of energy in total cost was negligible (Statistics Canada, KLEMS data set).

A third factor linking the U.S. and Canadian food processing industries is their trade relationship. After Japan, Canada is the U.S.'s second largest export market for processed food and beverages. Between 1990 and 1994, a total of 16.7 billion U.S. dollars worth of processed foods were exported to Canada, representing 15% of the U.S. total processed food exports. Conversely, the U.S. is Canada's most important destination for manufactured foods: Canada exported to the U.S. 19.6 billion U.S. dollars worth of processed food over the 1990-94 period. In both countries, the principal export and import products are meats, frozen fish, and canned fruits and vegetables (Ruppel and Harris 1996, Agriculture Canada 1997). In the U.S., recent trends show that the fastest export growth in percentage terms is in highly processed products such as frozen bakery, chewing gum, and soft drinks which, unsurprisingly, are industries with relatively low trade volumes (Ruppel and Harris 1996). In Canada, Barkman (1992) reported that between 1961 and 1986, the export of highly and semi-processed products grew at a faster rate that did the low processed and unprocessed products.

2.2 Trends in the U.S. and Canadian Food and Beverage Sectors

Table 2.1 characterizes the evolution of the U.S. and Canadian food manufacturing sector, in terms of real value of shipments and annual proportionate percentage change, between 1962 and 1994. In order to summarize and compare the performance of the U.S. and Canadian food sectors, simple average proportional rates of growth are computed for four sub-periods and presented in table 2.2. These two tables reveal that in both the U.S. and Canada, the real value of processed food and beverage shipments grew rapidly during the 1960s, stopped by the first oil crisis in 1973. Immediately after 1973, the average proportionate rate of growth declined substantially in both countries. The real value of shipments declined in the U.S. from an annual average proportionate rate of 3.29 % in the 1962-73 period to -0.97 % in the 1974-81 period. In Canada, the average annual proportionate rate of growth declined from 4.77% to -0.29% between the 1962-73 and 1974-81 periods. While the Canadian processed food and beverage sector performed better in terms of average proportionate growth in real shipment value during the 60's and 70's, this advantage was reversed in the early 1980's. From 1982 to 1987, U.S. food and beverage shipments grew at an average proportionate real rate of 2.44 % per annum. In contrast, Canada experienced an average annual proportionate growth rate of 2.00 %. Furthermore, when the effect of exchange rate is ignored, the Canadian growth rate was only 0.99% over this same 1982-87 period. After 1988, the U.S. continued to outperform Canada, with a simple average annual proportionate growth rate of 1.54 % between 1988 and 1994, compared with 0.46 % in Canada.

Trends in number of firms and values of shipment per firm provide an indication of structural change in the U.S. and Canadian food sector during this time. As table 2.3 shows, the number of establishments declined by 36% in the U.S. and by 51% in Canada between 1967 and 1992. From 1987 to 1992, however, the number of establishments increased slightly in the U.S. while a continuous decline was observed in Canada. Although the number of firms decreased over these years, average firm size, measured in terms of value of shipment per establishment, increased continuously. Finally, table 2.3 reveals that in terms of real value of shipment per establishment, Canadian food processors are on average smaller than in the U.S.

These findings are in line with U.S. and Canadian business cycles since 1960. Rapid growth in the value of food shipments occurred during the 1960's, when both the U.S. and Canadian economies were expanding. Conversely, the decline in the growth of food shipments in both countries was concomitant with the economic recessions of 1973/74 and early 1980. However, the extent to which economic contraction and expansion impacted the U.S. and Canadian food manufacturing sectors differed. The mid-70s recession appears to have been more harmful in the U.S. than in Canada. Food shipments decline by an average annual rate of -0.97% in the U.S. during 1974 to 1981, compared to -0.17% in Canada. When the U.S.-Canadian exchange rate is not taken into account, Canada enjoyed a positive average growth rate of 1.15%. However, the U.S. had the stronger growth rate in value of shipments following the early 1980's recession. From the early 1980's to the early 1990's, low interest rates and tax incentive programs characterized the U.S. business climate, and the U.S. food sector benefited from that climate. As a result, the value of food shipments grew quickly in the U.S., while the Canadian rate of growth lagged behind.

It is important to keep in mind that these findings picture the food and beverage sector as a whole. Different trends and patterns are observable within the sub-industries composing this sector. For instance, according to Barkman (1992), the number of establishments have increased in the meat and frozen fruit industries between 1970 and 1988, although the total number of establishments decreased in the whole food manufacturing over that period.

Table 2.1: Real Value of Shipments (billions of 1992 U.S. dollars) and Annual Proportionate Change, U.S. and Canadian Food Manufacturing

Year	US	% change	Canada	% change
1962	247.69	3.43	18.64	0.93
1963	254.10	2.59	19.66	5.45
1964	265.13	4.34	21.04	7.02
1965	269.53	1.66	21.65	2.92
1966	280.15	3.94	23.06	6.49
1967	294.42	5.09	24.16	4.77
1968	298.84	1.50	24.40	0.90
1969	307.46	2.88	25.14	3.13
1970	312.98	1.80	27.16	8.01
1971	318.79	1.86	27.74	2.16
1972	338.79	6.27	30.34	9.37
1973	352.87	4.15	32.20	6.13
1974	354.64	0.50	33.02	2.53
1975	345.11	-2.69	32.52	-1.52
1976	346.67	0.45	33.61	3.36
1977	348.28	0.47	32.06	-4.60
1978	361.69	3.85	32.26	0.61
1979	351.38	-2.85	32.55	0.92
1980	334.16	-4.90	31.47	-3.31
1981	325.55	-2.58	31.67	0.63
1982	328.74	0.98	31.26	-1.30
1983	334.76	1.83	31.82	1.79
1984	344.26	2.84	31.57	-0.78
1985	350.56	1.83	31.32	-0.77
1986	372.22	6.18	32.99	5.33
1987	375.77	0.95	35.56	7.78
1988	387.88	3.22	38.27	7.63
1989	396.74	2.28	38.61	0.88
1990	394.59	-0.54	38.18	-1.13
1991	399.89	1.34	38.62	1.17
1992	406.73	1.71	37.43	-3.07
1993	415.84	2.24	35.79	-4.39
1994	418.89	0.73	35.26	-1.48

Sources:

- U.S. Bureau of Census (1997), *Manufacturer's Shipments, Inventories, and Orders* (htpp\\www.census.gov\ftp\pub\indicators\www\m3\index.htm).
- Statistics Canada (various years). *Manufacturing Industries of Canada, National and Provincial areas*

Table 2.2: Simple Average Proportionate Growth in Real Value of Shipments, U.S. and Canadian Food Manufacturing

Year	US (%)	Can (%)
1967-73	3.29	4.77
1973-81	-0.97	-0.17
1982-87	2.44	2.01
1988-94	1.57	-0.057

Table 2.3: Number of Establishments and Value of Shipments per Establishment (Constant 1992 US dollars)

Year	Number of establishments				Shipments/establishment	
	US		Canada		US	Canada
	number	%	number	%	million $	million $
1967	32518		6737		9,059,367	3,586,344
1972	28183	-13.33	5377	-20.19	12,023,002	5,643,208
1977	26656	-5.42	4211	-21.68	13,073,134	7,613,486
1982	22310	-16.30	3518	-16.46	14,733,176	8,885,043
1987	20583	-7.74	3440	-2.22	18,260,196	10,337,977
1992	20798	1.04	3282	-4.59	18,993,287	11,406,347

Sources:

- Statistical Abstract of the U.S. (1978, 1987, 1996), *Manufactures Summary by Industry Group.*
- Statistics Canada (various years). *Manufacturing industries of Canada, National and Provincial areas.*

2.3 Market Concentration and Scale

The high degree of concentration prevailing in the U.S. and Canadian food industry is illustrated in tables 2.4a and 2.4b, which categorize the number of establishments and value of shipments by employment size group. The largest plants account for a large proportion of the total value of food shipments. For instance in 1992, about 17% of total U.S. food shipment value was accounted for by the largest group of firms (with one thousand employees or more). This group represented less than 1% of the total number of U.S. establishments. Similarly in 1994, about 20% of total Canadian shipments were accounted for by 1.2% of the total number of Canadian establishments. Firms with an average of one hundred employees or more represented only 17% of the total number of establishments in the U.S. in 1992, but produced over two thirds of total shipments. In Canada, about 60% of the total value of shipments was attributed to establishments with one hundred employees or more. This category accounted for only about 15% of the total number of Canadian establishments. Tables 4a and 4b also reveal that, in both countries, the food processing sector is characterized by a large number of small plants. Establishments with 20 or fewer employees represented about 55% of the total number of establishments in the U.S. in 1992, and about 50% of the total number in Canada in 1994.

Table 2.4a. Market Concentration in the U.S.

Employment Size Group	Establishments		Value of Shipments (1992 U.S. $)	
	(number)	(%)	(million)	(%)
1-4	5767	27.73	2046	0.50
5-9	2886	13.88	3793.4	0.93
10-19	2816	13.54	8304.6	2.04
20-49	3569	17.16	31301.6	7.67
50-99	2147	10.32	46984.4	11.52
100-249	2139	10.28	97147.9	23.81
250-499	916	4.40	82756.8	20.29
500-999	401	1.93	66179.9	16.22
1000-2499	147	0.71	57734.6	14.15
2500-	10	0.05	11713.5	2.87
Total	**20798**	**100**	**407962.7**	**100**

Source: U.S. Bureau of Census (1992), *Census of Manufactures.* Department of Commerce

Table 2.4b. Market Concentration in Canada

Employment Size Group	Establishments		Value of Shipments (1992 Can $)	
	(number)	(%)	(million)	(%)
1-4	496	15.77	217.70	0.44
5-9	450	14.30	557.54	1.13
10-19	562	17.86	1816.61	3.67
20-49	686	21.81	5125.90	10.35
50-99	458	14.56	8747.55	17.66
100-199	266	8.46	9085.99	18.35
200-499	190	6.04	13821.62	27.91
500-	38	1.21	10149.78	20.50
Total	**3146**	**100**	**49522.69**	**100**

Source: Statistics Canada (1994), *Manufacturing Industries of Canada, National and Provincial Areas.*

2.4 Studies of U.S. and Canadian Food Manufacturing Productivity

Most studies of food processing productivity are derived from a larger, economy-wide analysis of a single country. Several studies, on the other hand, have investigated a specific industry in the food processing sector.

Bilateral comparisons have been conducted in which the competitiveness of the Canadian food industry was examined, with the U.S. as a benchmark. However, researchers have not been able to agree on the size of the productivity gap, as inconsistent methods have been used to measure productivity. Results tend to suggest that Canada has a slower growth rate than does the United States. Table 2.5 summarizes studies comparing productivity in the Canadian and U.S. food processing sectors (Hazledine, 1991).

Although little consensus has been reached on the appropriate productivity measure, results reported in table 2.5 reveal that, overall, food manufacturing in Canada is substantially less productive than in the U.S. The ratios of Canadian to U.S. labor productivity in the first three columns show that labor productivity is lower in Canada. In the fourth column, Rao and Lempriere (1992) report a widening productivity gap between the U.S. and Canada from 1965 to 1985. In the last column, the total factor productivity (TFP) index, which is a ratio of the output index to the input index, is reported. Unlike the labor productivity measure, the TFP measure suggests that U.S. and Canadian productivity were very similar in 1982.

The explanation traditionally provided for the lower Canadian productivity is the difference in scale, measured in terms of real value of shipments per plant. Canadian plants are on average smaller than in the U.S. As shown in table 2.3, U.S. firms produced an average of 19 million U.S. dollars worth of goods in 1992, compared to 11 million U.S. dollars worth produced in Canada in the same year. Other factors that could contribute to lower productivity in Canada include differences in research and development expenditures and differences in capacity utilization.

Although interesting, the point-in-time productivity measures presented above are unreliable. From year to year, productivity differences between the two countries fluctuate due to business cycle changes or other exogenous shocks. Firms operate at different levels of capital utilization at different points on the business cycle, affecting the productivity measures we observe. Rates-of-growth comparisons based on time-series data are therefore more appropriate.

Saulnier (1993) used multifactor accounted-based productivity measures to compare U.S. and Canadian productivity in each of the groups composing the manufacturing sector as a whole. Multifactor productivity reflects the increase in production not accounted for by the growth of all measured inputs. A detailed discussion of multifactor productivity is provided in chapter 3. Saulnier's multifactor productivity figures for the U.S. and Canadian food processing industries are reported in table 2.6 and figure 2.1. Three sub-periods can be distinguished. First, from 1961 to 1973, long-term productivity growth in the food and beverage sector was higher in the U.S. than in Canada, while the opposite pattern is observed in the 1974-79 period. Overall, however, the U.S. and Canada followed similar productivity trends until 1979. That year was a point of departure for a widening productivity gap between the two countries, as figure 2.1 reveals. Productivity increased quickly in the U.S., while in Canada growth stayed constant on average, even decreasing after 1986. These data support the findings reported in section 2.2.

Table 2.5: Productivity in Canadian Food Processing, Relative to U.S. Productivity

Method used	**Value-added per employee**				**TFP**
Author	Frank	Baldwin and Gorecki	Hazledine and Guiton	Rao and Lempriere[1]	Hazledine, Guiton, Wall
Year	1972	1979	1982	1965 and 1985	1982
Productivity (Canada/U.S.)	0.734	0.531	0.581	1965: 0.808 1985: 0.733	0.986

1) Includes the tobacco industry

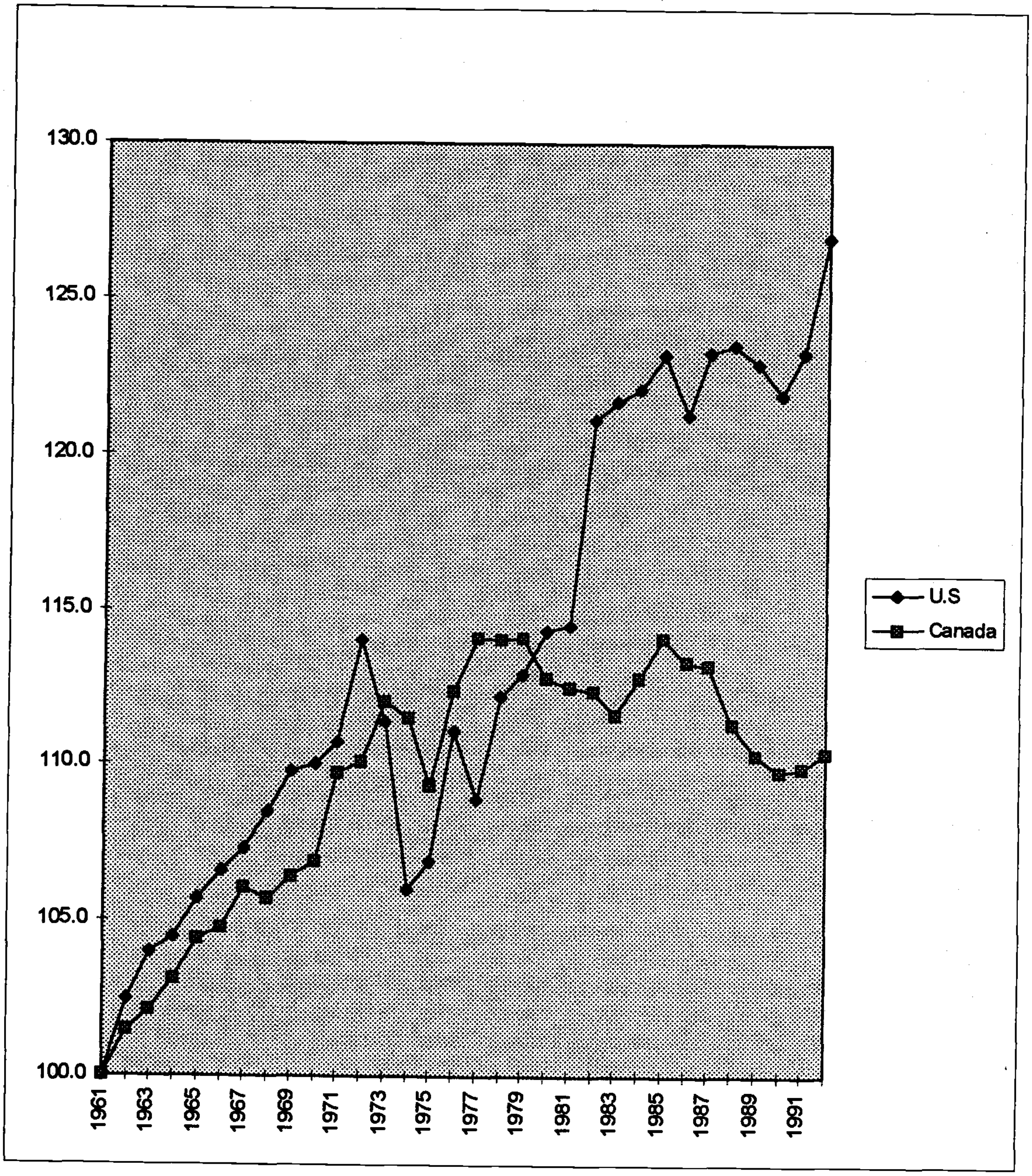
Source: Hazledine, T. (1991), *Productivity in Canadian food and beverage industries. Canadian Journal of Agricultural Economics,* vol.39

Table 2.6: U.S. and Canadian Multifactor Productivity Growth (1961-1992)

Year	U.S	Canada
1961	100.0	100.0
1962	102.5	101.5
1963	104.0	102.1
1964	104.5	103.1
1965	105.7	104.4
1966	106.6	104.8
1967	107.3	106.1
1968	108.5	105.7
1969	109.8	106.4
1970	110.0	106.9
1971	110.7	109.7
1972	114.0	110.1
1973	111.4	112.0
1974	106.0	111.5
1975	106.9	109.3
1976	111.1	112.4
1977	108.9	114.1
1978	112.2	114.0
1979	112.9	114.1
1980	114.3	112.8
1981	114.5	112.5
1982	121.1	112.4
1983	121.7	111.6
1984	122.1	112.8
1985	123.2	114.1
1986	121.3	113.3
1987	123.3	113.2
1988	123.5	111.3
1989	122.9	110.3
1990	121.9	109.8
1991	123.3	109.9
1992	127.0	110.4

Source: Saulnier, M.A. (1993) *Comparability of Multifactor Productivity Estimates Canada and the U.S.* Statistics Canada, National Accounts and Analytical Studies, System of National Accounts, Input-Output Division Technical Series #60-E.

Figure 2.1: U.S. and Canadian Multifactor Productivity Growth



Source: Saulnier, M.A. (1993) *Comparability of Multifactor Productivity Estimates Canada and the U.S.* Statistics Canada, National Sccounts and Analytical Studies, System of National Accounts, Input-Output Division Technical Series #60-E.

Chapter 3: Economic Assessment Framework

The trend towards trade liberalization has raised concerns about the ability of a sector in one country to compete with that in another. The concept of competitiveness has thus become an important issue. Competitiveness can be interpreted in several ways, as reported by Coffin et al. (1993) in their literature review on competitiveness. Two lines of thought can be drawn from their review. A first approach defines competitiveness in terms of market shares or profits. This measure, however, is restricted to the firm level and might provide contradictory results: for example, firm A might earn higher profit than firm B, while B occupies a larger market share than does A. Under the second approach, competitiveness is measured through factor productivity. This method provides a measure of productive efficiency between countries (Rao and Lempriere, 1992). In addition, it reflects growth on a long-term basis, supporting the idea that productivity growth is the principal factor influencing a country's competitiveness (McCorriston and Sheldon, 1994).

Productivity growth originates from: (i) an increase in technical efficiency; (ii) an improvement in scale efficiency; and (iii) technological progress (Kalaitzandonakes et al, 1994). The last comes from the introduction of new processes or new inputs. Given a level of output and input, technological change can, in turn, reduce production cost or increase profit (Antle and Capalbo, 1988).

With this background in mind, how is productivity growth measured? The basic concept in measuring productivity growth is Total Factor Productivity (TPF), which is an index of aggregate output over an index of aggregate input. Total Factor Productivity Growth (TFPG) is the residual of total output or cost growth after accounting for the rate of change of all other variables, except time itself (Morrison 1992, p. 382).

3.1 Measurement of Technological Change

3.1.1 Primal Measure

The derivation of TFPG has its foundation in the theory of cost and production economics. Assuming long-run equilibrium and a competitive market in inputs, consider the following production function: $Y = f(\mathbf{X}, t)$ where Y is total output, **X** is a vector of input, and t is time.[1]

By taking the natural log of this function and differentiating with respect to time, the rate of growth of output can be measured (Antle and Capalbo 1988, p. 35). That is,

$$\frac{d\ln Y}{dt} = \frac{1}{Y}\left[\frac{\partial f}{\partial t} + \sum_i \frac{\partial f_i}{\partial X_i}\frac{dX}{dt}\right] \text{ or,}$$

$$\frac{d\ln Y}{dt} = \frac{\partial \ln f}{\partial t} + \frac{1}{Y}\left[\sum_i \frac{\partial f_i}{\partial X_i}\frac{dX}{dt}\right] \qquad (3.1)$$

where $\frac{\partial f_i}{\partial X_i}$ is the marginal product of X_i and $\frac{\partial \ln f}{\partial t}$ is the primal rate of technological change.

Under the assumptions of perfect competition and profit maximization, the firm equates the price of each output to its marginal cost, and the price of each input to the value of its marginal product. Mathematically, $P_y = MC$ and $W_i = MP_iP_y$, where P_y is the price of output, W_i the price of input i, and MP_i the marginal product of the i^{th} input. Consequently, equation (3.1) becomes:

$$\frac{d\ln Y}{dt} = \frac{\partial \ln f}{\partial t} + \sum_i S_i \frac{d\ln X_i}{dt} \qquad (3.2)$$

[1] A time trend captures the impacts on output that are not captured by other independent variables or are difficult to quantify (Rao and Lempriere 1992, p. 24).

where $S_i = \frac{W_i X_i}{P_y Y}$.

Equation (3.2) can be rewritten as

$$\varepsilon_{Yt} = \frac{\partial \ln f}{\partial t} = \frac{d\ln Y}{dt} - \sum_i S_i \frac{d\ln X_i}{dt} \tag{3.3}$$

Therefore, assuming constant returns to scale and perfect competition, ε_{Yt} (the partial elasticity of output with respect to time) isolates technological change. It is the total output growth net of the rate of growth of inputs weighted by revenue shares.

An equivalent notation can be found by substituting the cost minimization first order condition $\frac{\partial f}{\partial X_i} = \frac{W_i}{\partial C / \partial Y}$ into equation (3.3) and using $\varepsilon_{CY} = \frac{\partial C}{\partial Y}\frac{Y}{C}$, the elasticity of cost with respect to output (Antle and Capalbo, 1988, p. 35, eq. 2.9):[2]

$$\varepsilon_{Yt} = \frac{\partial \ln f}{\partial t} = \frac{d\ln Y}{dt} - \sum_i \varepsilon_{CY}^{-1} \frac{W_i X_i}{C} \frac{d\ln X_i}{dt} \tag{3.3'}$$

In other words, technological change is the rate of change in output minus a scale-adjusted index of the rate of change in inputs (Antle and Capalbo, 1988, p. 35).

3.1.2 Dual Measure

Assuming maximizing behavior, duality theory postulates that a production and a cost function dual to each other exist. For a well-behaved production function, the corresponding cost function is:

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[2] Or, $\varepsilon_{yt} = \frac{\partial \ln f}{\partial t} = \frac{d \ln Y}{dt} - \sum_i \varepsilon_{cy}^{-1} S_i \frac{d \ln X_i}{dt}$ because under CRTS, $W_i X_i / C = W_i X_i / P_y Y$

$$C = g(Y,\mathbf{W},t)$$

where **W** is a vector of input prices.

As previously, the rate of change of total cost is obtained by taking the natural log of both sides of the equation and differentiating with respect to time (Antle and Capalbo, 1988, p. 35):

$$\frac{d\ln C}{dt} = \frac{d\ln}{dt}[g(Y,\mathbf{W},t)] = \frac{1}{C}\left[\frac{\partial g}{\partial t} + \sum_i \frac{\partial g}{\partial W_i}\frac{dW_i}{dt} + \frac{\partial g}{\partial Y}\frac{dY}{dt}\right]$$

$$\frac{d\ln C}{dt} = \frac{\partial \ln g}{\partial t} + \sum_i \frac{\partial \ln g}{\partial \ln W_i}\frac{d\ln W_i}{dt} + \frac{\partial \ln g}{\partial Y}\frac{dY}{dt} \tag{3.4}$$

in which $\frac{\partial \ln g}{\partial t} = \varepsilon_{Ct}$ (the partial elasticity of cost with respect to time) represents the dual rate of technological change.

By Shephard's Lemma, $\frac{\partial \ln C}{\partial \ln W_i}\frac{C}{W_i} = X_i$. Therefore, $\frac{W_iX_i}{C} = \frac{\partial \ln C}{\partial \ln W_i}$. Assuming perfect competition in input markets, equation (3.4) can be written as:

$$\varepsilon_{Ct} = \frac{\partial \ln g}{\partial t} = \frac{d\ln C}{dt} - \sum_i S_i \frac{d\ln W_i}{dt} - \frac{\partial \ln g}{\partial Y}\frac{dY}{dt} \tag{3.5}$$

where $S_i = W_iX_i/C = W_iX_i/P_yY$ under constant returns to scale (CRTS).

Using $\varepsilon_{CY} = \frac{\partial C}{\partial Y}\frac{Y}{C}$, equation (3.5) becomes:

$$\varepsilon_{Ct} = \frac{\partial \ln g}{\partial t} = \frac{d\ln C}{dt} - \sum_i S_i \frac{d\ln W_i}{dt} - \varepsilon_{CY}\frac{\partial \ln Y}{\partial t} \tag{3.5'}$$

In other words, the dual rate of technological change is the rate of change of total cost less an index of the rate of change of factor prices less a scale effect (Antle and Capalbo 1988, p. 36). The scale effect ε_{cy} is important to consider because assuming CRTS (i.e. $\varepsilon_{CY} = 1$) in the presence of returns to scale will over- or under-estimate the rate of technologicalchange, as the scale effect and technological change could be confounded in the TFPG measure (Nadiri and Schankerman 1981, p.385).

ε_{Yt} and ε_{Ct} are related to each other as follows. First, taking the total differential of the natural log of $C = \sum_i WiXi$ with respect to time gives (Antle and Capalbo, 1988, p. 36, eq. 2.11):

$$\frac{d\ln C}{dt} = \sum_i S_i \frac{d\ln W_i}{dt} + \sum_i S_i \frac{d\ln X_i}{dt}. \tag{3.6}$$

Manipulating (3.6) with (3.3') and (3.5') and rearranging gives the relation between the primal and dual rates of technological change (Antle and Capalbo, 1988 p. 36, eq. 2.11):

$$-\frac{\partial \ln C}{\partial t} = \left(\frac{\partial \ln C}{\partial \ln Y}\right)\frac{\partial \ln f}{\partial t}$$

$$\text{or } -\varepsilon_{Ct} = \varepsilon_{CY} * \varepsilon_{Yt} \tag{3.7}$$

Therefore, the primal and the negative of the dual rates of technological change are equal if and only if the technology is constant returns to scale (Antle and Capalbo, 1988, p. 36).

3.2 Two Approaches for Measuring Productivity

A survey of existing methods in the area of productivity research reveals two principal approaches for measuring productivity: (i) the accounting method, using index number theory; and (ii) econometric techniques. An overview of the two methods is presented below.

3.2.1 The Index Number or Growth Accounting Method

An index number expresses the quantity or price relative to a base year. Under the growth accounting approach, a TFPG index is calculated using input and output indexes. Aggregation of inputs and outputs into indexes involves the choice of an indexation procedure, implying an underlying aggregator function and thus a set of economic assumptions. The link between the growth accounting approach and the economic theory of production is summarized by Cowing and Stevenson's (1981) statement that "in the area of "exact" index numbers, a unique correspondence exists between the type of index used to aggregate outputs and inputs, and the structure of the underlying technology."

For instance, using Laspeyres or Paasches indexes to measure productivity implies a linear or Leontief production function (Antle and Capalbo 1988).[3,4] As these indexes are computed by keeping a weight quasi-fixed relative to a base year, they are subject to several limitations (Sudit and Finger, 1981). The limitations include: (i) possible aggregation biases, thus over- or under-estimating the change in TFP; (ii) failure to conform to Fisher's reversal rule.[5]

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[3] A Laspeyres price (quantity) index is a weighted aggregate price index in which the weight for each item is its current period quantity (price).

[4] A Paasches price (quantity) index is a weighted aggregate price index in which the weight for each item is its base period quantity (price).

[5] Fisher's reversal rule states that the product of factor price and quantity indexes should yield total cost between any two periods. This a desirable property for appropriate separation of price and quantity effects.

A more flexible index is the continuous Divisia index, which allows weights to vary from year to year. Advantages of using the Divisia include (Sudit and Finger,1981): i) unbiasedness under certain assumptions regarding the underlying production function; ii) the reproductive property; and iii) conformance to Fisher's reversal rule.[6,7]

Since TFP = Y/X, the proportionate rate of TFP growth is:

$$\dot{TFP} = \dot{Y} - \dot{X} \tag{3.8}$$

in which $\dot{Y} = dY/dt$ and $\dot{X} = dX/dt$.

If growth rates $\dot{Y}$ and $\dot{X}$ are Divisia indexes, they are defined as:

$$\dot{Y} = \sum_j \frac{P_j Y_j}{P_y Y} \dot{Y}_j \tag{3.9}$$

where $\dot{Y} = dY/dt$ and $\dot{Y}_j = dY_j/dt$.

Thus also,

$$\dot{X} = \sum_i \frac{W_i X_i}{C} \dot{X}_i \tag{3.10}$$

where $\dot{X} = dX/dt$ and $\dot{X}_i = dX_i/dt$, and where j indexes outputs and i indexes inputs.

Using Divisia indexes, productivity growth is therefore defined as the difference between a weighted rate of growth of outputs and a weighted rate of growth of inputs, where the weights are the value shares of the respective inputs and outputs (Denny, Fuss and Waverman, 1981).

[6] Also called a superlative index.

[7] The Divisia satisfies the reproductive property because: "a discrete Divisia index of discrete Divisia indexes is a discrete Divisia index of the components" (Sudit and Finger 1981). This property is particularly important when aggregate variables are obtained by means of aggregation of subaggregates.

A discrete approximation of the continuous Divisia index is needed because most economic data are observable in discrete intervals. A recommended discrete approximation of the Divisia index is the Tornqvist index, which is exact for a homogeneous translog production function (Diewert, 1976). A translog functional form, in turn, is a second-order differential approximation to any arbitrary twice continuously differentiable function (Christensen, Jorgenson and Lau, 1973). A translog function is attractive because it is a flexible functional form and allows for variable returns to scale.

Using the Tornqvist index as an approximation to the Divisia index, $\dot{Y}$ and $\dot{X}$ can be approximated as:

$$\ln(Y_t/Y_{t-1}) = 1/2 \sum(S_{jt} + S_{jt-1}) * \ln(Y_{jt}/Y_{jt-1}) = \dot{Y}$$

$$\ln(X_t/X_{t-1}) = 1/2 \sum(S_{it} + S_{it-1}) * \ln(X_{jt}/X_{jt-1}) = \dot{X}$$

Substituting into $\dot{TFP} = \dot{Y} - \dot{X}$ gives (Antle and Capalbo 1988, p. 56, eq. 2.45'):

$$\dot{TFP} = \ln(TFP_t/TFP_{t-1}) = \ln(Y_t/Y_{t-1}) - \ln(X_t/X_{t-1}) = \dot{Y} - \dot{X} \qquad (3.11)$$

Under CRTS, the TFPG measure under the growth accounting approach (equation 3.11) is equivalent to the one derived from economic theory (equations 3.3' and 3.5'). Following Denny, Fuss, and Waverman (1981, pp. 193-196), the equivalence between the two results is demonstrated as follows.

Recall from (3.3') that technological change is represented by

$$\varepsilon_{Yt} = \frac{\partial \ln f}{\partial t} = \frac{d\ln Y}{dt} - \sum_i \varepsilon_{CY}^{-1} \frac{W_i X_i}{C} \frac{d\ln X_i}{dt}.$$

Using the Divisia index defined in (3.9), ε_{Yt} can be rewritten as

$$\varepsilon_{Yt} = \dot{Y} - \varepsilon_{CY}^{-1} \dot{X}$$

Substituting $\dot{Y}$ from this last equation into $\dot{TFP} = \dot{Y} - \dot{X}$ gives

$$\varepsilon_{Yt} = \dot{TFP} + (1 - \varepsilon_{CY}^{-1})\dot{X} \qquad (3.12)$$

where $(1 - \varepsilon_{CY}^{-1})$ is a scale effect (Denny, Fuss, and Waverman 1981, p. 193, eq. 15). Therefore, if production is subject to CRTS (where $\varepsilon_{CY} = 1$), $\varepsilon_{Yt} = \dot{TFP}$.

Similarly, the dual measure is derived as follows. In (3.5'), the dual measure of technological change was represented by

$$\varepsilon_{Ct} = \frac{\partial \ln g}{\partial t} = \frac{d\ln C}{dt} - \sum_i S_i \frac{d\ln W_i}{dt} - \varepsilon_{CY}\frac{d\ln Y}{dt}$$

Using (3.9), this equation can be rewritten as (Denny et al. 1981, p. 194, eq. 22):

$$\varepsilon_{Ct} = \frac{d\ln C}{dt} - \sum_i S_i \frac{d\ln W_i}{dt} - \varepsilon_{CY}\dot{Y} \qquad (3.13)$$

Substituting (3.11) and (3.12) into the primal-dual relation $-\varepsilon_{Ct} = \varepsilon_{CY} * \varepsilon_{Yt}$ (equation 3.7), we get

$$\dot{TFP} = -\varepsilon_{Ct} + (1 - \varepsilon_{CY})\dot{Y}$$

As before, if CRTS holds ($\varepsilon_{CY} = 1$) then $-\varepsilon_{Ct} = \dot{TFP}$.

In conclusion, the use of the growth accounting method to approximate technical progress is possible at the cost of the following assumptions (Antle and Capalbo 1988, p.56):

1. Competitive markets for all inputs and output.
2. Constant returns to scale.

3. Extended Hicks-neutral technological change.
4. Input-output separability in the underlying transformation function.

The first assumption is essential for the maximizing behavioral conditions underlying the derivation of the TFPG measure. The second assumption is necessary for assuming that the sum of the weights equals one in the primal and dual measures, and for conformance between the index approach and production theory as discussed above. [8] The third and fourth assumptions are required for the existence of separate aggregate output and input indexes needed for computing a TFPG index (Cowing and Stevenson 1981, p. 7, Antle and Capalbo 1988, p. 58).

3.2.2 Econometric Approach

An alternative to index number theory is the use of econometric techniques to measure TFP growth. Econometric methods allow us to test hypotheses about the shape of the production technology as well as about non-constant returns to scale and about neutrality in technological change. Therefore, the strong assumptions underlying index number methods can be relaxed.

Once again, duality theory allows us to estimate either the production function or the cost function. Choice between either one of these functions depends on whether output is endogenous or exogenous (Christensen and Green, 1976). A cost function is often more attractive than a production function because the output upon which input decisions are based is considered to be exogenous.

Suppose the following cost function implicitly represents the technology:

$$C = f(\mathbf{W}, Y, t; \beta) + \mu,$$

[8] Otherwise, the TFPG measure will not identically measure the shifts in technology (Denny, Fuss, and Waverman, 1981, p.196).

where β is a vector of unknown parameters to be estimated and μ is a vector of random disturbances.

From Shephard's Lemma, a set of input demand functions whose parameters are a subset of those in the cost function can be derived from the cost function itself (Antle and Capalbo, 1988 p. 60). For the ith input,

$$S_i = g_i(W_i, Y, t; \beta_i) + \mu_i$$

where S_i is a cost share and β_i a subset of the parameters in β. The resulting system of simultaneous equations can enhance the degrees of freedom in empirical work and enhances the statistical precision of the estimates. The sum of the cost shares equals one, but this does not impose restrictions on the degree or constancy of returns to scale (Christensen and Greene, 1976).

The econometric task is to obtain estimates of the β vector. In order to do that, one will have to decide upon statistical assumptions for the error terms and choose a functional form and an estimator.

3.3 Technical Bias

3.3.1 Input Bias

Technological change is said to be biased when the shift of the production or cost function resulting from the adoption of new technology affects an optimal factor proportion (X_i/X_j) or factor cost share ($P_iX_i/\sum P_iX_i$). In contrast, technological change is Hicks-neutral if the marginal rate of technical substitution (MRTS) is independent of time. Antle and Capalbo (1988) note that Hicks neutrality does not imply and is not implied by input homotheticity.

Holding the factor price ratio constant, the following expression measures bias in terms of its effect on the optimal factor proportion or the cost minimizing input ratio (Biswanger, 1978; Antle and Capalbo, 1988):

$$\beta_{ij}^{c}(Y,\mathbf{W},t) = \frac{\partial \ln X_i(Y,W,t)}{\partial t} - \frac{\partial \ln X_j(Y,W,t)}{\partial t} \tag{3.14}$$

where i, j are elements of input vector **X**, $i \neq j$, and $X_i(Y,W,t)$ is the compensated factor demand function obtained by applying Shephards' Lemma to cost function C(Y,**W**,t). If $\beta_{ij}^{c} > 0$ then technological change is input X_j saving; if $\beta_{ij} < 0$, technological change is input X_j using; and if $\beta_{ij} = 0$, technological change is neutral.

The drawback of (3.14) is that it requires pairwise comparison between factors of production. As a consequence, only n-1 factors pairs can be considered. A generalization that allows us to measure bias for each factor of production is to express bias in terms of factor shares, because a decrease in the use of factor i relative to all others results in a decrease in its share. That is,

$$\beta_{i}^{c}(Y,\mathbf{W},t) = \frac{\partial \ln S_i(Y,W,t)}{\partial t} \tag{3.15}$$

where S_i (Y,**W**,t) is the optimal factor cost share. If $\beta_i^c > 0$, technological change is factor i using; if $\beta_i^c < 0$, it is factor i saving; and finally if $\beta_i^c = 0$, it is Hicks-neutral.

Cowing and Stevenson (1981, p. 7, footnote 6) argue that a violation of the separability and neutral technological change assumptions does not preclude TFPG measurement. This argument is based on the finding of Caves et al. (1980).

3.3.2 Scale Effects Adjustment

The homotheticity assumption underlying (3.14) and (3.15) assures independence between the cost shares S_i and output level Y, implying independence between Y and β_i. In the absence of homotheticity, a change in the scale of production alters optimal factor proportions or cost shares, so that β_i^c would be composed of a scale effect (movement along the expansion path) and an input bias effect (shift of expansion path) (Antle and Capalbo 1988, p. 40). Therefore, the adjusted measure for technical bias is (Antle and Capalbo 1988, p. 41, eq. 2-20).

$$\beta_i^* = \beta_i - \left(\frac{\partial \ln S_i}{\partial \ln Y}\right)\varepsilon_{CY}^{-1}\frac{\partial \ln C}{\partial t} \qquad (3.16)$$

Under the homotheticity assumption, the scale effect $(\partial \ln S_i / \partial \ln Y)$ is zero and $\beta_i^* = \beta_i$.

3.4 Temporary Equilibrium

Another strong assumption underlying our development of the TPFG so far is that firms always produce at their long-run equilibrium point. This assumption implies that firms instantaneously adjust all inputs to their long-run equilibrium levels. That is, firms always equate the value of the marginal products of all inputs to their respective prices. In the short run, however, exogenous shocks such as business cycle fluctuations, unexpected demand shocks, or sudden changes in factor prices imply that quasi-fixed inputs adjust only partially to their full equilibrium levels (Berndt 1990; Berndt and Fuss 1986).[9] Since capital is an important factor of production in the food processing industry, TFPG measurement has to be adjusted to accommodate temporary equilibrium. Therefore, an

[9] Quasi-fixed inputs are inputs that are fixed in the short run but variable in the long run, such as capital and equipment.

alternative framework that distinguishes variable from quasi-fixed inputs is needed when using a short-run cost function.[10]

3.4.1 Statistical Model

Following Morrison (1986, p. 54), let's first define the variable cost function as

$$VC = h(Y, \mathbf{W}, t, \mathbf{K}) \tag{3.17}$$

where K is a vector of quasi-fixed input quantities. Short run total cost is simply the sum of variable and fixed costs (Morrison 1986, p. 54):

$$C = h(Y, \mathbf{W}, t, \mathbf{K}) + \Sigma_k p_k K_k \tag{3.18}$$

where p_k is a vector of market rental prices of quasi-fixed inputs.

Under temporary equilibrium, firms do not equate the value of the marginal product of the quasi-fixed inputs to their respective market prices, but rather to their shadow prices (Bernt and Fuss, 1986). Using the variable cost function, the shadow price Z_k of quasi-fixed inputs is computed as $Z_k = -\partial h / \partial K$. Under temporary equilibrium, this shadow price of quasi-fixed inputs Z_k should be used instead of the market price W_k for MFPG measurement. Using Z_k, the shadow cost function is defined as:

$$C^* = h(Y, t, \mathbf{W}, \mathbf{K}) + \Sigma_k Z_k K_k \tag{3.19}$$

The shadow cost function represents the long run cost if the firm faces factor prices **W** and Z_k and produces Y (Berndt and Fuss 1986, p.17).

[10] In a short run function, some inputs are fixed at levels other that their full equilibrium, while in the long run all inputs are at their full equilibrium values (Bernt and Fuss 1986).

Differentiating the natural log of (3.18) with respect to time and rearranging gives the rate of technological change ε_{Ct}^{F}, where superscript F stands for fixed factors (Morrison 1986, p. 55, eq. 3):

$$\varepsilon_{Ct}^{F} = \frac{d\ln C}{dt} - \sum_i \frac{W_iX_i}{C}\frac{d\ln W_i}{dt} - \frac{\partial \ln C}{\partial Y}\frac{dY}{dt} - \sum_k \frac{p_kK_k}{C}\frac{d\ln p_k}{dt} - \sum_k \frac{(p_k - Z_k)K_k}{C}\frac{d\ln K_k}{dt}$$

Let's now define $\varepsilon_{CK} = \frac{(p_k - Z_k)K_k}{C} = \frac{\partial \ln C}{\partial \ln K}$ and $\frac{\partial \ln C}{\partial Y}\frac{dY}{dt} = (\varepsilon_{CY}^{SR})\frac{d\ln Y}{dt}$, where $\varepsilon_{CY}^{SR} = 1 - \Sigma\varepsilon_{CK}$. This last expression is derived from the relationship between the cost elasticity along the variable and the short run total cost function when fixed inputs are involved (Morrison, 1992):

$$\varepsilon_{CY}^{LR} = \varepsilon_{CY}^{SR} + \varepsilon_{CY}^{LR}\Sigma_k \partial \ln C / \partial \ln K_k = \varepsilon_{CY}^{SR} + \varepsilon_{CY}^{LR}\Sigma\varepsilon_{CK} \tag{3.20}$$

With long-run CRTS, $\varepsilon_{CY}^{LR} = 1$, thus $\varepsilon_{CY}^{SR} = 1 - \Sigma\varepsilon_{CK}$ and ε_{Ct}^{F} can be rewritten as:

$$\varepsilon_{Ct}^{F} = \frac{d\ln C}{dt} - \sum_i \frac{W_iX_i}{C}\frac{d\ln W_i}{dt} - (1 - \Sigma\varepsilon_{CK})\frac{d\ln Y}{dt} - \sum_k \frac{p_kK_k}{C}\frac{d\ln p_k}{dt} - \sum_k \varepsilon_{CK}\frac{d\ln K_k}{dt} \tag{3.21}$$

In other words, the dual rate of technological change is the difference between the time rate of change in costs, a scale effect, and the rate of change of quasi-fixed factors market price after reevaluating the share of fixed input at its shadow price to incorporate non-optimal utilization. ε_{Ct}^{F} in (3.21) is related to ε_{Ct} in (3.5') as follows (Morrison 1992, p. 385, equation 5):

$$\varepsilon_{Ct}^{F} = \varepsilon_{Ct} + \sum_{k} \varepsilon_{CK}\left[\frac{d\ln K_k}{dt} - \frac{d\ln Y}{dt}\right] \qquad (3.22)$$

In the long run, $Z_k = p_k$ so that $\varepsilon_{CK} = 0$ and $\varepsilon_{Ct}^{F} = \varepsilon_{Ct}$.

From Ohta (1975), an equivalent expression for ε_{Ct}^{F} can be derived under CRTS using $C = \sum W_i X_i + \sum p_k K_k$. Taking the natural log of both sides of this equation and differentiating with respect to time yields (Morrison 1986, p. 55, eq. 4)

$$\frac{d\ln C}{dt} =$$

$$\sum_{i} \frac{W_i X_i}{C}\frac{\partial \ln W_i}{\partial t} + \sum_{i} \frac{W_i X_i}{C}\frac{\partial \ln X_i}{\partial t} + \sum_{k} \frac{p_k K_k}{C}\frac{\partial \ln p_k}{\partial t} + \sum_{k} \frac{p_k K_k}{C}\frac{\partial \ln K_k}{\partial t} \qquad (3.23)$$

Substituting (3.23) into (3.21) and rearranging gives (Morrison 1986, p. 56, eq. 5):

$$\varepsilon_{Ct}^{F} = \varepsilon_{CY}^{SR}\frac{d\ln Y}{dt} - \sum_{i} \frac{W_i X_i}{C}\frac{\partial \ln X_i}{dt} - \sum_{k} \frac{Z_k K_k}{C}\frac{\partial \ln K_k}{\partial t} \qquad (3.24)$$

The dual rate of technological change under short run equilibrium is the difference between a scale-adjusted rate of change in output and the share-weighted sum of changes in inputs, in which quasi-fixed inputs are evaluated at their shadow price.

As before, equation (3.24) can be rewritten as (3.22):

$$\varepsilon_{Ct}^{F} = \varepsilon_{Ct} + \sum_{k} \varepsilon_{CK}\left[\frac{d\ln K_k}{dt} - \frac{d\ln Y}{dt}\right].$$

3.4.2 Capacity Utilization

Temporary equilibrium results in variation in capacity utilization. Recall that in long run equilibrium, firms are producing under full utilization of all inputs at all points in time. Under temporary equilibrium this is no longer true. Firms can be operating below capacity (fixed inputs are underutilized) or above capacity (fixed inputs are overutilized). When variations in capacity utilization are not considered, the resulting TFPG measure will over- or under-state the true TFPG. The variation in the utilization rates of quasi-fixed inputs is related to ε_{Ct}^{F} as follows (Morrison 1986, pp. 56-57):

First, using $[(p_k - Z_k)K_k] / C = \varepsilon_{CK}$, the expression $\varepsilon_{CY}^{SR} = 1 - \sum\varepsilon_{CK}$ can be rewritten as (Morrison 1986, p. 57, eq. 7):

$$1 - \sum\varepsilon_{CK} = \frac{C - \sum(p_k - Z_k)K_k}{C} = \frac{h + \sum Z_k K_k}{C} = \frac{\text{Shadow cost}}{C}$$

Therefore,

$$1 - \sum\varepsilon_{CK} = \frac{C^*}{C} = \text{Capacity Utilization (CU)} = \varepsilon_{CY}^{SR} \qquad (3.25)$$

where C* is the shadow cost function as defined in equation (3.19).

Dividing both sides of (3.24) by $(1 - \sum\varepsilon_{CK})$ and substituting from (3.25) gives an adjusted measure of technological change when firms deviate from full capacity (Morrison 1986, p. 57, eq. 8):

$$\varepsilon_{Ct}^{A} = \frac{\varepsilon_{Ct}^{F}}{1 - \sum\varepsilon_{CK}} = \frac{d\ln Y}{dt} - \sum_i \frac{W_i X_i}{C^*}\frac{\partial\ln X_i}{dt} - \sum_k \frac{Z_k K_k}{C^*}\frac{\partial\ln K_k}{\partial t} \qquad (3.26)$$

ε_{Ct}^{A} provides a "true" measure of TFPG which purges the temporary equilibrium effect and thus reflects the impact of technical progress only.

Equation (3.26) can also be obtained by manipulating the shadow cost function (3.19) instead of short run total cost function (3.18). That is, differentiating the natural log of (3.19) with respect to time gives:

$$\frac{d\ln C^*}{dt} = \frac{\partial \ln C^*}{\partial t} + \varepsilon_{CY}\frac{d\ln Y}{dt} + \sum_i \frac{W_iX_i}{C^*}\frac{\partial \ln W_i}{\partial t} + \sum_k \frac{Z_kK_k}{C^*}\frac{\partial \ln Z_k}{\partial t} \qquad (3.27)$$

Substituting (3.27) into

$$\frac{d\ln C^*}{dt} = \sum_i \frac{W_iX_i}{C^*}\frac{\partial \ln X_i}{\partial t} + \sum_i \frac{W_iX_i}{C^*}\frac{\partial \ln W_i}{\partial t} + \sum_k \frac{Z_kK_k}{C^*}\frac{\partial \ln K_k}{\partial t} + \sum_k \frac{Z_kK_k}{C^*}\frac{d\ln Z_k}{dt}$$

(which is derived from the definition $C^* = \Sigma_i W_i X_i + \Sigma_k Z_k K_k$) gives equation (3.26).

From (3.26), this adjusted TFPG measure is the traditional TFPG measure divided by a capacity utilization term. In the long run, CU = 1 and $\varepsilon_{Ct}^{A} = \varepsilon_{Ct}^{F}$. In the short run, however, CU will be greater or less than one depending upon whether the shadow price is greater or lower than the market rental price. If $Z_k > P_k$, the fixed input is overvalued relative to its market price. In that case, the firm is overusing its fixed input, implying capacity shortage. From (3.25), capacity utilization can be seen as a short run scale elasticity, where the deviation of ε_{CY}^{SR} from one is due to returns to the fixed inputs (Morrison 1992). CU can also be interpreted as a ratio of short run to long run returns to scale (from equations 3.20 and 3.25). According to Morrison (1986), this interpretation of ε_{Ct}^{A} is consistent with Ohta's view, namely that "to isolate technological change, one must adjust for returns to scale, which involves short run returns". Adjusting the traditional TFPG measure by a capacity utilization expression revalues the share of each fixed input to its shadow price. In this way, the true marginal contribution of the fixed inputs to production is recognized.

3.5 Bilateral Model

In order to compare the productivity difference across two countries at a point in time, a framework that allows for bilateral comparison is needed. Following the framework developed by Denny, Fuss, and May (1981), let the following cost function represent the technology at a point of time:

$$C_j = G_j\,(W_j, Y_j,\, t_j),$$

where subscript j refers to country j.

Assuming CRTS and that the cost function in each country has common elements, this function can be approximated as:

$$\log C_j = G(\log W_j\,,\ \log Y_j\,,\ \log t_j\,, D),$$

where G is a quadratic function and D a vector of dummy variables.

The production cost difference between two countries is derived by applying Diewert's (1976) quadratic lemma to the above function[11] (Denny et al., p. 393, eq. 3):

$$\Delta\log C \;=\; \log C_j \;-\log C_s =$$

$$\frac{1}{2}\left[\left.\frac{\partial G}{\partial D_j}\right|_{D=j} + \left.\frac{\partial G}{\partial D_s}\right|_{D=s}\right][D_j - D_s] +$$

$$\frac{1}{2}\sum_i\left[\left.\frac{\partial G}{\partial \log W_i}\right|_{W_i=W_{ij}} + \left.\frac{\partial G}{\partial \log W_i}\right|_{W_i=W_{is}}\right][\log W_{ij} - \log W_{is}] + \tag{3.28}$$

$$\frac{1}{2}\left[\left.\frac{\partial G}{\partial \log Y}\right|_{Y=Y_j} + \left.\frac{\partial G}{\partial \log Y}\right|_{Y=Y_s}\right][\log Y_j - \log Y_s]$$

[11] The quadratic lemma states that the difference between the values of a quadratic function evaluated at two points is equal to the average of the gradient evaluated at both points multiplied by the difference between the points.

where j indexes country, s indexes the reference country, and i indexes an input in country j. The right-hand side of (3.28) consists of three terms: the country effect (or the efficiency differential between two countries), the input price effect, and the output effect, respectively.

By the CRTS assumption and perfect competition, $\frac{\partial G}{\partial \log Y} = \frac{\partial \log C}{\partial \log Y} = 1$ and $\frac{\partial G}{\partial \log W_i} = \frac{\partial \log C}{\partial \log W_i} = S_i$.

Equation (3.28) can be rewritten as (Denny et al. 1981, p. 394):

$$\Delta \log C = \frac{1}{2}\left[\left.\frac{\partial G}{\partial D_j}\right|_{D=j} + \left.\frac{\partial G}{\partial D_s}\right|_{D=s}\right][D_j - D_s] + \frac{1}{2}\sum_i [S_{ij} + S_{is}][\log W_{ij} - \log W_{is}] + [\log Y_j - \log Y_s] \qquad (3.29)$$

For simplification in notation, we define Φ_{js} as the efficiency differential between the two countries, or country effect. Then we have (Denny et al. 1981, p. 394, eq.9)

$$\Phi_{js} = \frac{1}{2}\left[\left.\frac{\partial G}{\partial D_j}\right|_{D=j} + \left.\frac{\partial G}{\partial D_s}\right|_{D=s}\right][D_j - D_s] = [\log C_j - \log C_s] - \frac{1}{2}\sum_i [S_{ij} + S_{is}][\log W_{ij} - \log W_{is}] - [\log Y_j - \log Y_s] \qquad (3.30)$$

In other words, the country effect is the log difference in cost levels between the two countries after taking account of the log difference of an index of outputs and the log difference of an index of input prices, holding outputs and input prices in each country constant (Hazilla and Kopp 1988, p.208).

Φ_{js} is defined as the first-order dual measure of the interspatial productivity difference between country j and reference country s at a particular point of time (Hazilla and Kopp 1988, p.212). It is also called the interspatial discrete Divisia index of productivity difference or the Tornqvist index of cost efficiency gap (Antle and Capalbo 1988, p.65; Conrad, 1989, p.1148). Conrad (1989) defines Φ_{js} as a cost efficiency gap between countries. It represents the relative difference in cost if, for instance, in a given year, U.S. output (the reference country) is produced in Canada given U.S. output and input price levels. A negative Φ_{js} would imply that the transfer of production from the U.S. to Canada would result in a cost reduction. In that case, the U.S. would have a productivity gap compared to Canada.

The main advantage of using equation (3.30) is its simplicity: it can be computed directly using observable data on costs, input prices, and outputs in the two countries with no need for econometric estimation. Econometric techniques, however, are needed to determine the source of technology gap between countries, and to analyze the sources of productivity differences. A system of simultaneous equations can be formed using the cost share equations, an equation for rate of productivity growth in the base country, and an equation for the difference in cost efficiency between the two countries.

A second-order Taylor series expansion of equation (3.30) can be used in order to include a second-order interaction effect.[12] This alternative measure was derived by Denny and Fuss and requires econometric techniques. Denny and Fuss showed that the interspatial productivity measure will differ from the discrete Divisia index approximation (Φ_{js}) if any of the second-order parameters of a Taylor series approximation differs between the two countries. However, Hazilla and Kopp (1988) found that the second-order bias is small, implying that the measurement of Φ_{js} from the first-order approximation is not seriously biased by ignoring the second-order effect.

[12] Also called the general second-order accounting equation.

Chapter 4: Data, Econometric Model, and Estimation

Empirical implementation of the theoretical framework developed in chapter 3 requires constructing a comparable data set in the U.S. and Canada as well as specifying an econometric model. The first section of this chapter provides information on the source and construction of the data set. Next, issues to consider in choosing a functional form are discussed. In the last section, I present the econometric model used to assess the productivity growth rate in the U.S. and Canada.

4.1 Food Manufacturing Data Series

The U.S. Bureau of Labor and Statistics Canada provided the food manufacturing data series for total cost, output quantity, and prices of capital, labor, energy, materials, and services (KLEMS) from 1962 to 1992. Total cost is expressed in current dollars, while output quantity and input prices are Tornqvist indexes. In order to reduce the number of parameters to be estimated and increase the degrees of freedom, service prices are combined with labor prices and energy prices with material prices. The combinations are the weighted averages of the separate prices, in which the weights used are the budget shares of the respective inputs.

4.1.1 Purchasing Power Parities

Assessing productivity gains in a bilateral framework requires using comparable data sets across countries. Therefore, it is essential to make sure of: (i) conformity between the methodological approaches used in the two countries to assemble the data; and (ii) concordance between the U.S. and Canadian food and beverage classifications. Saulnier (1993) has analyzed these issues at the two-digit manufacturing industry level and concludes that the U.S. and Canadian data sets are comparable in terms of methodology and industrial classification.

Input price and output quantity indexes reported by each country are equal to one in the base year. Used in conjunction with one another, this implies incorrectly that the U.S. and Canadian food processing industries each produced the same quantity of output and faced the same input prices in the base year. As a consequence, the proportionate output quantities and input prices in non-base years are also misleading. Conversion factors are thus required to achieve inter-country comparability in the two data sets. The conversion factor adjusts for the differences in the quantities of inputs and output that can be purchased with the same amount of money in the U.S. and Canada. Inter-country competitiveness is affected greatly by differences in input and output prices across countries.

A Purchasing Power Parity (PPP) is an international price index used to compare the price of the same bundle of commodities in two different countries (Lempriere and Rao, 1992). For instance, using the U.S. as the numeraire country, the PPP for input i (output) gives the number of Canadian dollars required to purchase an amount of input (output) that costs one U.S. dollar in the U.S. (Jorgenson and Kuroda, 1990). Thus, a PPP is just the conversion factor we seek to adjust a base-year index value in Canada relative to a base-year value in the United States.

4.1.2 Source and Construction of PPPs

The computation of PPPs is tedious, requiring a laborious collection and weighting of prices for very specific commodities that are similar across countries. Such data are not easily available, as they involve international agreements on product definition and other methodological issues. The most extensive set of PPPs to date was developed by Kravis, Heston, and Summers (1978), who estimated PPPs for more than one hundred categories of consumption goods in a wide variety of countries. Unfortunately, Canada was not included in their work. At a more aggregate level, PPPs for a country's entire

GDP are published by the OECD. Statistics Canada has extended the OECD's work, computing PPPs between the U.S. and Canada for the main components of GDP from 1982 to 1993. According to Saulnier (1993), PPP computation for specific input categories is problematic as it tends to infringe on proprietary confidentiality. As a consequence, several studies of international productivity have been based on the authors' own estimates of input PPPs. For instance, Conrad (1989) has constructed PPPs between Japan, Germany, and the U.S. for capital, labor, and materials used in manufacturing industries, based on the approach of Kravis, Heston, and Summers (1978).

Following Conrad (1989), I estimated Canada-U.S. PPPs for inputs used in the food manufacturing sector, employing the U.S. as numeraire country. The main idea is to compute a PPP for each input in the base year in order to shift the Canadian price index series relative to that in the U.S. The PPP for a given input is defined as:

$$PPP = \frac{W_{0,\,can}}{W_{0,\,us}} \tag{4.1}$$

that is, the ratio of the Canadian to the U.S. price for the given input in the base year. Using the market exchange rate, each PPP is converted to U.S. dollars. After conversion, the PPP for the given input is thus defined as the number of U.S. dollars required in Canada to purchase the same quantity of input costing one dollar in the U.S. (Jorgenson and Kuroda, 1990). Once the base-year PPP is estimated, the Canadian input price series is adjusted as

$$\frac{W_{t,\,can}}{W_{0,\,us}} = \frac{W_{t,\,can}}{W_{0,\,can}} * \left(\frac{W_{0,\,can}}{W_{0,\,us}}\right)^{adj} = \frac{W_{t,\,can}}{W_{0,\,can}} * PPP \tag{4.2}$$

where $PPP = \left(\frac{W_{0,\,can}}{W_{0,\,us}}\right)^{adj}$ is the PPP for the input in question expressed in terms of U.S.dollar equivalents. The U.S.- comparable input price series $\frac{W_{t,\,can}}{W_{0,\,us}}$ is then deflated by the U.S. Producer Price Index (PPI) in order to eliminate purely nominal inter-year price changes.

A similar approach was used to adjust the Canadian output quantity and capital quantity indexes. The U.S.- comparable output quantity series for Canada is obtained by computing,

$$\frac{Q_{t,\,can}}{Q_{0,\,us}} = \frac{(V_{0,\,can})(Q_t/Q_0)_{can}}{V_{0,\,us}} * \frac{P_{o,\,can}}{P_{o,\,us}} = \frac{(V_{0,\,can})(Q_t/Q_0)_{can}}{V_{0,\,us}} * PPP_Q \qquad (4.3)$$

where Q is output quantity, P is output price, $V_0 = P_0Q_0$ is value of food processing industry shipments in the base year, and PPP_Q is the PPP for manufactured food products (provided by Statistics Canada and the Bureau of Census). Observe that $P_0Q_t = V_0(Q_t/Q_0)$.

Similarly, the corrected capital quantity index for Canada is given by

$$\frac{K_{t,\,can}}{K_{0,\,us}} = \frac{(S_{0,\,can})(K_t/K_0)_{can}}{S_{0,\,us}} * \frac{W_{o,\,can}}{W_{o,\,us}} = \frac{(S_{0,\,can})(K_t/K_0)_{can}}{S_{0,\,us}} * PPP_k \qquad (4.4)$$

where K is quantity of capital, W_K is service price of capital, $S_0 = W_0K_0$ is capital expenditure in the base year (Statistics Canada and Bureau of Labor Statistics), and PPP_K is the PPP for capital.
In (4.4), $W_0K_t = S_0(Q_t/Q_0)$.

The following information was used to create PPP proxies for labor, capital, and material prices in a benchmark year:

- The labor PPP was computed as the ratio of the Canadian to the U.S. average hourly wage rate in the food processing industry in 1992. These data were provided by the BLS and Statistics Canada.

- The capital PPP was estimated as $PPP_k = q_{can}(r+\delta)_{can} / q_{us}(r+\delta)_{us}$, where q is acquisition price of capital, r is opportunity cost of capital, and δ is capital depreciation rate. In this formula, q(r+δ) is a used as the service price of capital. It differs from the capital service price formula in Christensen and Jorgerson (1969) in that it ignores property tax rates (for which no information is readily available) and capital gains rates, which would differ little between the two countries. The PPP for gross capital formation, published by Statistics Canada, was used as a proxy for q_{can}/q_{us}, while the long-term government bond yield in each country in the base year was used for r_{can} and r_{us}. Finally, depreciation rate δ was set equal to 1/12 in both countries. This capital PPP is the same as that used to adjust the capital quantity series in equation (4.4).
- The output PPP, namely PPP_Q, used in equation (4.3) was estimated for the Canadian and U.S. food manufacturing industries by Rao and Lempriere (1992). Lacking information on relative material (raw farm product, packaging, and energy) prices in the two countries, I used PPP_Q as a proxy for the material PPP.

4.1.3 Research and Development (R&D) Expenditures

The National Science Foundation provided data on food and beverage (including tobacco) R&D expenditures in the U.S. from 1962 to 1992. R&D expenditures are defined as operating expenses such as depreciation, wages and salaries, materials and supplies, and maintenance and repairs. These expenditures are company-funded R&D performed within the company, excluding government funds and R&D contracted to any outside organizations. For 1963 and the period 1975-80, however, R&D expenditures include federal funds because separate data were not available. In 1962, 1964-1966, and 1968, no R&D expenditure data were reported. I approximated R&D expenditures in those years by multiplying company-funded R&D expenditures in the entire manufacturing sector by the percentage share of manufacturing R&D expenditures accounted for by the food industry.

Company-financed R&D expenditures in the Canadian food and beverage industry (including tobacco) were obtained from Statistics Canada for the period 1962-92. In contrast to the U.S., Canadian R&D expenditures include acquisition costs of new capital as well as operating costs. Canadian R&D expenditures were converted to U.S. dollars, then deflated with the U.S. Producer Price Index.

4.2 Econometric Model

4.2.1 Functional Form

The specification of a statistical model to represent technology in the food industry requires the choice of a general and flexible functional form. A general functional form would provide estimates of productivity measures while placing as few prior restrictions as possible on the technology (Chambers, 1988). A flexible functional form is required in order to obtain own and cross price elasticities over an appropriate set of possible parameter values. An inflexible form, in contrast, prescribes the value or at least a range of values of critical parameters (Lau, 1986).

Theoretical consistency of the functional form with the properties of the cost function in neoclassical theory is important. The variable cost function is consistent with theory if and only if the following properties are satisfied. The variable cost function is (McFadden, 1978; Hazilla and Kopp, 1986):

1. Non-decreasing in the prices of variable inputs;
2. Non-increasing in quasi-fixed factors;
3. Non-decreasing in output;
4. Homogeneous of degree one in the prices of variable inputs;
5. Symmetric with respect to the second partial derivatives in variable input prices;

6. Symmetric with respect to the second partial derivatives in quasi-fixed factors;
7. Concave in the prices of variable inputs;
8. Convex in quasi-fixed factors.

Therefore, the functional form should meet these requirements for an appropriate choice of parameters. Computational facility is another criterion to consider in the choice of a functional form (Lau, 1986).

4.2.2 Translog

The transcendental logarithmic function introduced by Christensen, Jorgenson, and Lau (1973) is a second-order Taylor's series approximation in logarithms to an arbitrary cost function (Berndt, 1991). The translog model has became popular in empirical studies for its attractive properties: it is a flexible functional form and does not impose restrictions on the degree of returns to scale or on homotheticity. In addition, the translog is linear in parameters, making mathematical manipulation easy.
Let the general form of the variable cost function be

$$VC = G\,(W_l,\, W_m,\, Y,\, K/Y,\, R/Y) \qquad (4.5)$$

where W_l and W_m are, respectively, the price of labor and materials, Y is output, R/Y denotes research intensity (i.e. R&D expenditures per unit of output) and K/Y is quantity of capital per unit of output. K and R are expressed per unit of output to reduce multicollinearity among the regressors.

The variable commonly used to represent technical progress is a time trend. In this study, we use R&D rather than time to represent the level of technological development in U.S. and Canada. The reasons are: (i) time is highly correlated with the independent variables in the variable cost function (4.5) and (ii) R&D is a better proxy for technology than is time. Indeed, process and product innovation resulting from R&D contribute to technical progress which, in turn, is a determinant of productivity growth. There is substantial empirical evidence in the literature on the positive relation between productivity growth and R&D. For instance, Griliches (1980) analyzed the effect of R&D expenditures on productivity growth in U.S. manufacturing firms during the 1970's. He concluded that R&D contributes positively to productivity growth. Furthermore, he reported that privately financed R&D is more effective, at the firm level, than is government-financed R&D. Terleckyj (1980) also found a significant effect of privately financed R&D on productivity growth.

Technological improvement resulting from R&D is not instantaneous but rather involves a time lag. The correct specification of the R&D lag structure remains, however, an issue: no consensus has been reached either on the length of the lag or on its distribution (Mansfield, 1980).

The translog variable cost function is therefore written as:

$$\begin{aligned}\ln VC = {} & \alpha_0 + \beta_L \ln W_l + \beta_M \ln W_m + \lambda_R(\ln R_{t-s} - \ln Y_{t-s}) + \tau_K(\ln K - \ln Y) + \theta_Y \ln Y + \\ & 0.5\,(\gamma_{LL}\ln^2 W_l + \gamma_{MM}\ln^2 W_m) + 0.5(\gamma_{LM}\ln W_l \ln W_m) + 0.5\,\theta_{YY}(\ln Y)^2 + \\ & 0.5\lambda_{RR}(\ln R_{t-s} - \ln Y_{t-s})^2 + 0.5\lambda_{KK}(\ln K - \ln Y)^2 + \\ & \beta_{LY}(\ln W_l \ln Y) + \beta_{MY}(\ln W_m \ln Y) + \beta_{LR}(\ln W_l(\ln R_{t-s} - \ln Y_{t-s})) + \\ & \beta_{MR}(\ln W_m(\ln R_{t-s} - \ln Y_{t-s})) + \beta_{LK}(\ln W_l(\ln K - \ln Y)) + \\ & \beta_{MK}(\ln W_m(\ln K - \ln Y)) + \theta_{YR}(\ln Y(\ln R_{t-s} - \ln Y_{t-s}) + \\ & \tau_{KY}(\ln Y(\ln R_{t-s} - \ln Y_{t-s})) + \tau_{KR}(\ln K - \ln Y)(\ln R_{t-s} - \ln Y_{t-s}) \qquad (4.6)\end{aligned}$$

Note that subscript s in the R variable indexes for length of the lag.

Homogeneity of degree one in input prices implies the following restrictions on (4.6):

$$\begin{aligned}&\beta_L + \beta_M = 1; \quad \gamma_{LL} + \gamma_{LM} = 0;\\ &\beta_{LR} + \beta_{MR} = 0; \quad \beta_{LY} + \beta_Y = 0; \qquad (4.7)\end{aligned}$$

Symmetry implies:

$$\gamma_{ij} = \gamma_{ji} \text{ and } \beta_{ij} = \beta_{ji} \text{ where i,j = L, M for } i \neq j. \tag{4.8}$$

Gains in efficiency can be realized by estimating the optimal or cost-minimizing factor demand (cost share) equations obtained by logarithmically differentiating (4.6) with respect to the exogenous input prices and using Shephard's Lemma (Berndt, 1991):

$$S_l = \beta_L + \gamma_{LL}(\ln W_l) + \gamma_{LM}(\ln W_m) + \beta_{LR}(\ln R_{t-s} - \ln Y_{t-s}) + \beta_{LY}\ln Y + \beta_{LY}(\ln K - \ln Y)$$
$$S_m = \beta_M + \gamma_{MM}(\ln W_m) + \gamma_{LM}(\ln W_l) + \beta_{MR}(\ln R_{t-s} - \ln Y_{t-s}) + \beta_{MY}\ln Y + \beta_{MY}(\ln K - \ln Y) \tag{4.9}$$

Since the sum of the two cost shares in (4.9) is always one, the sum of the error terms in S_l and S_m will always be equal to zero, implying that the covariance matrix of the error terms is singular and nondiagonal. The common procedure to handle this singularity problem is to drop one of the factor share equations. The parameter estimates obtained are independent of which share equation is deleted as long as maximum likelihood procedures are employed (Berndt, 1991). Therefore, arbitrarily deleting the material share equation and imposing the restrictions for homogeneity in input prices (as in 4.8) in both the variable cost and labor share equations gives:

$$\begin{aligned}
&\ln VC(W_l, Y_t, K/Y_t, R_{t-s}/Y_{t-s}) - \ln W_m = \\
&\alpha_0 + \beta_L(\ln W_l - \ln W_m) + \lambda_R(\ln R_{t-s} - \ln Y_{t-s}) + \theta_Y \ln Y_t + \tau_K(\ln K - \ln Y_t) + \\
&0.5\,\gamma_{LL}(\ln W_l - \ln W_m)^2 + 0.5\,\theta_{YY}(\ln Y_t)^2 + 0.5\tau_{KK}(\ln K - \ln Y_t)^2 + \\
&0.5\lambda_{RR}(\ln R_{t-s} - \ln Y_{t-s})^2 + \\
&\beta_{LR}(\ln W_l - \ln W_m)(\ln R_{t-s} - \ln Y_{t-s}) + \beta_{LY}(\ln W_l - \ln W_m)(\ln Y_t) + \\
&\beta_{LK}(\ln W_k - \ln W_m)(\ln K - \ln Y_t) + \theta_{YR}(\ln R_{t-s} - \ln Y_{t-s})(\ln Y) + \\
&\tau_{KR}(\ln K - \ln Y)(\ln R_{t-s} - \ln Y_{t-s}) + \tau_{KY}(\ln K - \ln Y)(\ln Y)
\end{aligned} \tag{4.6a}$$

$$S_l = \beta_L + \gamma_{LL}(\ln W_l - \ln W_m) + \beta_{LR}(\ln R_{t-s} - \ln Y_{t-s}) + \beta_{LY}\ln Y + \beta_{LK}(\ln K - \ln Y) \tag{4.9a}$$

Assuming perfect competition, output or shadow value equations that represent the producer's optimizing behavior can be appended to (4.6a) and (4.9a) in order to increase efficiency and precision of the estimates (Morrison, 1990; Berndt and Hesse, 1986). The output price equation is an algebric representation of the profit-maximizing first-order condition, namely output price equal marginal cost. It is obtained by logarithmically differentiating equation (4.6a) with respect to Y and setting output price equal to marginal cost, i.e. $\partial VC/\partial Y$. The output price equation is:

$$S_y = \frac{\partial \ln VC}{\partial \ln Y} = \frac{P*Y}{VC} =$$

$$\theta_Y - \tau_K + \theta_{YY}\ln Y_t - \tau_{KK}(\ln K - \ln Y_t) + \beta_{LY}(\ln W_l - \ln W_m) -$$
$$\beta_{LK}(\ln W_k - \ln W_m) + \theta_{YR}(\ln R_{t-s} - \ln Y_{t-s}) - \tau_{KR}(\ln R_{t-s} - \ln Y_{t-s}) +$$
$$\tau_{KY}(\ln K - 2\ln Y) \qquad (4.10)$$

where P*Y is the value of shipment.

Assuming long-run constant returns to scale, an alternative representation of the producer's optimal behavior is given by a shadow value equation. Logarithmically differentiating (4.6a) with respect to quasi-fixed capital, and setting its shadow price Z_k equal to marginal cost, gives the shadow value equation

$$S_k = \frac{\partial \ln VC}{\partial \ln K} = \frac{Z_k * K}{VC} =$$

$$\tau_K + \tau_{KK}(\ln K - \ln Y_t) + \beta_{LK}(\ln W_k - \ln W_m) + \tau_{KR}(\ln R_{t-s} - \ln Y_{t-s}) +$$
$$\tau_{KY}(\ln Y) \qquad (4.11)$$

According to Morrison (1990), long-run constant returns to scale, one fixed factor, and competitive pricing imply that the ex-post return to the fixed factor equals $Z_kK = P*Y - VC$. Therefore, one can solve for shadow price Z_k in order to implement (4.11). As the difference between S_y and S_k is unity under long-run constant returns to scale, (4.10) and

(4.11) cannot be estimated together but should rather be considered as alternatives (Morrison, 1990).

4.2.3 Estimation

The construction of an estimable model is achieved by adding a random disturbance term to (4.6a), (4.9a), and (4.10). These equations are then jointly estimated as a simultaneous equation system, using Full Information Maximum Likelihood (FIML).

Since the translog is a second-order approximation of a general form, all variables are defined around an expansion point. In this study, I normalized around the sample mean by dividing each independent variable by its sample mean. Therefore, each variable is standardized to have a mean value of one. Normalization is equivalent to taking the sample mean of the right-hand-side variables as a point of approximation.

Separate regressions are performed for the U.S. and Canada. The main advantages of having two separate models rather than one pooled model are:

1. Multicollinearity in the separate model is reduced because: (i) no dummy variable needs to be included; and (ii) the U.S. and Canadian data sets tend to be correlated with one another;
2. The quadratic terms are not restricted to be the same in the two countries, as they would be in a pooled model.

In addition, estimating two separate models reduces heteroskedasticity and make the correction for serial correlation easier to implement. Finally, sets of restrictions specific to each country's production structure can be imposed when the models are estimated separately.

4.2.4 Rationality Restrictions on the Production Structure

The parametric model outlined in section 4.2.3 allows us to test for the production structure underlying the U.S. and Canadian food processing sector. Following Lau (1978) and Morrison (1986), the necessary and sufficient conditions for homotheticity, homogeneity, and constant returns to scale are derived below. These rationality restrictions can be tested using the likelihood ratio test:

$$LR = -2(L_R - L_U) \tag{4.12}$$

where L_R and L_U are respectively the log of likelihood statistic for the restricted and unrestricted model. LR is asymptotically distributed as a chi-square random variable with degrees of freedom equal to the number of independent restrictions being tested (Berndt, 1991).

The distinction between variable and quasi-fixed inputs under short-run equilibrium requires the set of parameters restrictions to be derived with respect to both output and fixed factor. Homotheticity prevails if the optimal factor proportions are independent of output, so that the expansion path is linear. Consequently, the variable cost function (4.6a) can be written such that factor prices are separable from output and fixed capital. In other words,

$$VC = h(Y,K)i(W_l, W_m, R) \tag{4.13}$$

In logarithmic terms,

$$\ln VC = \ln h(Y,K) + \ln i(W_l, W_m, R) \tag{4.14}$$

Therefore, homotheticity holds if $\frac{\partial \ln VC}{\partial \ln Y}$ and $\frac{\partial \ln VC}{\partial \ln K}$ are independent of W_l and W_m, holding R fixed. In terms of factors shares, homotheticity requires that $\frac{\partial \ln S_l}{\partial \ln Y} = 0$ and $\frac{\partial \ln S_m}{\partial \ln Y} = 0$, holding R fixed.

The variable cost function defined in (4.13) corresponds to a homogeneous technology if

$$VC = (Y^{1/\lambda 1} K^{1/\lambda 2})\, i(W_l, W_m, R) \tag{4.15}$$

where $\lambda_2 = k\lambda_1$

Therefore,

$$\begin{aligned} \ln VC &= \ln(Y^{1/\lambda 1}) + \ln(K^{1/k\lambda 1}) + \ln i(W_l, W_m, R) \\ &= 1/\lambda_1 (\ln Y) + 1/k\lambda_1 (\ln K) + \ln i(W_l, W_m, R) \end{aligned} \tag{4.16}$$

and,

$$\frac{\partial \ln VC}{\partial \ln Y} + \frac{\partial \ln VC}{\partial \ln K} = \text{constant.}$$

In other words, if output Y and fixed input K increase respectively by powers $(1/\lambda_1)$ and $(1/k\lambda_1)$, VC will increase by another power of λ_1 (Lau, 1978).

Constant returns to scale is obtained if, in addition to homotheticity, the technology is homogeneous of degree one. Therefore, $\frac{\partial \ln VC}{\partial \ln Y} + \frac{\partial \ln VC}{\partial \ln K} = 1$.

The complete set of parameter restrictions is

$$\begin{aligned} \frac{\partial \ln VC}{\partial \ln Y} &= \theta_Y - \tau_K + \theta_{YY} \ln Y_t - \tau_{KK} (\ln K - \ln Y_t) + \beta_{LY} (\ln W_l - \ln W_m) - \\ &\quad \beta_{LK}(\ln W_k - \ln W_m) + \theta_{YR} (\ln R - \ln Y_{t-s}) - \tau_{KR} (\ln R - \ln Y_{t-s}) + \\ &\quad \tau_{KY} (\ln K - 2\ln Y) \end{aligned}$$

$$\frac{\partial \ln VC}{\partial \ln K} = \tau_K + \tau_{KK}(\ln K - \ln Y_t) + \beta_{LK}(\ln W_k - \ln W_m) + \tau_{KR}(\ln R - \ln Y_{t-s}) + \tau_{KY}(\ln Y)$$

$$\frac{\partial \ln VC}{\partial \ln Y} + \frac{\partial \ln VC}{\partial \ln K} = \theta_Y + \ln Y_t(\theta_{YY} - \tau_{KY}) + \ln R(\theta_{YR}) + \ln K(\tau_{KY}) +$$

$$(\ln W_l - \ln W_m)(\beta_{LY}) + \ln Y_{t-s}(\theta_{YR})$$

Restrictions for homotheticity

$$\beta_{LY} = 0 \qquad (4.17)$$

Restrictions for homogeneity

In addition to homotheticity,

$$\theta_{YY} - \tau_{KY} = 0$$
$$\theta_{YR} = 0 \qquad (4.18)$$
$$\tau_{KY} = 0$$

Restriction for long-run constant returns to scale

In addition to homotheticity and homogeneity,

$$\theta_Y = 1 \qquad (4.19)$$

4.2.5 Technological change Effects of R&D Expenditure, Rates of Productivity Growth, Inter-Country Technology Differences, and Rates of Return to R&D

Recall from section 4.2.2 that process and product innovations resulting from R&D expenditures induce technological change, which in turn is a determinant of productivity growth. The primal and dual rate of technological change, as well as productivity growth, resulting from R&D expenditure can be computed from our system of equations. Let's first clarify the definition of technological change and productivity employed in this study, on the basis of Gollop and Roberts' (1981) terminology.

4.2.5.1) Primal and Dual Rates of Technological Change Associated with R&D in the Short-Run

In section 3.2.2, we found that technological change is the reduction in cost not accounted for by the growth in input prices and output. Technological change is represented by

$$-\partial \ln C/\partial t\,|_{W,Y} \tag{4.20}$$

Adapting this definition to a partial equilibrium framework where capital is held fixed, and using R&D rather than time to represent technology, gives:

$$-\partial \ln VC/\partial \ln R\,|_{W,Y,K} \tag{4.21}$$

Technological change results in a downward shift of the average cost curve. The translog representation of (4.21) is given by logarithmically differentiating (4.6a) with respect to R:

$$\varepsilon_{VCR} = -\frac{\partial \ln VC}{\partial \ln R} =$$

$$\lambda_R + \lambda_{RR}(\ln R_{t-s} - \ln Y_{t-s}) + \beta_{LR}(\ln W_l - \ln W_m) + \theta_{YR}\ln Y +$$
$$\tau_{KR}\ (\ln K - \ln Y_t) < 0 \tag{4.22}$$

ε_{VCR} is thus the percentage decrease in variable cost resulting from a percentage increase in R&D expenditures. Equivalently, it is the rate of reduction of average variable cost holding input prices, output, and stock of capital constant in a given year. We define ε_{VCR} as the technological change effect of R&D. From (4.22), ε_{VCR} is a function of R&D intensity, input prices, output, and the ratio of capital to output in a given year.

Alternatively, the primal rate of technological change associated with R&D expenditure is defined as the percentage increase in output associated with R&D growth, resulting in a shift of the production function. Following Antle and Capalbo (1988, p. 36, eq.2.11) and replacing time by R&D, the output-side productivity effect of R&D is related to (4.22) as follows:

$$\varepsilon_{YR} = \frac{\partial \ln Y}{\partial \ln R} = -\frac{\varepsilon_{VCR}}{\varepsilon_{VCY}} > 0 \qquad (4.23)$$

where ε_{VCY} is the log partial derivative of (4.6a) with respect to output [derived in (4.10)], and ε_{YR} is the percentage increase in output associated with one-percent increase in R&D.

The effect of a one-percent change in R and Y on the short-run *total* rather than variable cost can be computed from (4.22) and (4.10) as:

$$\varepsilon_{CR} = (\varepsilon_{VCR})(VC/C) \qquad (4.24)$$

$$\varepsilon_{CY}^{SR} = (\varepsilon_{VCY})(VC/C) \qquad (4.25)$$

Note that ε_{CR}^{SR} and ε_{VCR} in (4.22) can be used synonymously as the technological change effect of R&D. The former is the percentage reduction in total cost while the latter is the percentage reduction in variable cost, both associated with R&D growth holding capital fixed. Proofs of (4.24) and (4.25) are provided in the annex.

4.2.5.2) Long-Run Dual Productivity Growth Effect of R&D Expenditure

In contrast to technological change, productivity growth is a long-run equilibrium concept. A dual measure of productivity growth is the decrease in the long-run average total cost (LRAC) holding input prices constant (Gollop and Roberts, 1981, p.139):

$$- d\ln AC/dt\,|_W = \varepsilon_{ct} + (1 - \varepsilon_{cy})(d\ln Y/dt) \qquad (4.26)$$

Expression (4.26) indicates that productivity growth results from the direct effect of technological change (shift in the LRAC curve) plus the decrease in unit cost due to output expansion or reduction (movement along the LRAC curve). Technological change is thus a source of productivity growth. Technological change and productivity growth refer to the same concept only when long-run constant returns to scale, full equilibrium, and perfect competition prevail. Under these three conditions, technological change is the sole source of productivity growth because the right-hand expression in (4.26) goes to zero. Translating (4.26) into a long-run equilibrium framework that incorporates sub-equilibrium effects, and using R&D rather than time as a proxy for technology, gives:

$$-\left.\frac{d\ln AC}{d\ln R}\right|_{W} = \frac{VC}{C}\left[\frac{d\ln AVC}{d\ln R}\right] + \frac{p_k K}{C}\left[\frac{d\ln K}{d\ln R} - \frac{d\ln Y}{d\ln R}\right] \tag{4.27}$$

The dual rate of long-run productivity growth is the sum of the rates of change of average variable cost and capital-output ratio resulting from a change in R&D, each weighted by its respective input share. The first term in (4.27) is the reduction in unit variable cost associated with an R&D increase, weighted by the variable factor share; the second term is the reduction in per-unit capital associated with an R&D increase, weighted by the capital share. The growth in unit variable cost is given by:

$$-\left.\frac{d\ln AVC}{d\ln R}\right|_{W} = \left[\varepsilon_{VCR} + \varepsilon_{VCK}\left(\frac{d\ln K}{d\ln R} - \frac{d\ln Y}{d\ln R}\right)\right] \tag{4.28}$$

Substituting (4.28) into (4.27) gives

$$-\left.\frac{d\ln AC}{d\ln R}\right|_{W} = \frac{VC}{C}\left[\varepsilon_{VCR} + \varepsilon_{VCK}\left(\frac{d\ln K}{d\ln R} - \frac{d\ln Y}{d\ln R}\right)\right] + \frac{p_k K}{C}\left[\frac{d\ln K}{d\ln R} - \frac{d\ln Y}{d\ln R}\right] \tag{4.29}$$

Proofs of (4.27) and (4.28) are given in the annex. Note that dlnK/dlnR and dlnY/dlnR are equivalently given by (dK/K)/(dR/R) and (dY/Y)/(dR/R). Defining each term in (4.29):

- VC/C and (p_KK/C) are, respectively, the variable input share and capital share.
- ε_{VCR} is the percentage reduction in variable cost associated with a one-percent increase in R&D.
- ε_{VCK} is the elasticity of cost with respect to fixed capital (i.e. $\partial lnC/\partial lnK$). It is also given by $[(Z_k - p_k)K]/C$ (Morrison, 1986). This latter expression adjusts the expenditure share of capital to incorporate the impact of sub-equilibrium, where capital is valued at its shadow price rather than at its market price.
- dlnK/dlnR is the proportionate change of capital quantity induced by a one-percent change in R&D between two periods of time.
- dlnY/dlnR is the proportionate change of output quantity induced by a one-percent change of R&D between two periods of time.

Before turning to the economic interpretation of (4.29), first recall that under a short-run framework, deviation from full resource utilization precludes firms from operating at their full capacity, which corresponds to the minimum point on their short-run average cost (SRAC) curve. A change in capital stock occurs as a firm moves toward its long-run equilibrium level, where the SRAC curve is tangent to the LRAC curve at its minimum point, and which also corresponds to the minimum point on the LRAC curve by the constant returns to scale assumption.

Keeping these concepts in mind, the first expression in brackets is the reduction in unit variable cost associated with R&D expenditure, which in turn can be decomposed into two separate effects. First, the technological change effect of R&D expenditure, given by ε_{VCR}, is defined in (4.2.5.1). ε_{VCR} contributes directly to a decrease in variable cost, holding output, capital quantity, and input prices fixed. It is therefore a short-run effect. In contrast, expression $\varepsilon_{VCK}\left[\frac{dlnK}{dlnR} - \frac{dlnY}{dlnR}\right]$ in (4.29) is a long-run effect inasmuch as the stock of capital varies. ε_{VCK} (dlnK/dlnR) is the decrease in variable cost resulting from a percentage change in capital stock induced by R&D expenditure as the firm moves toward long-run equilibrium. This change in capital has an effect on output which affects cost. Once this output effect on variable cost is removed, the net reduction on variable cost brought about by a change in capital stock induced by R&D expenditure is obtained.

The last expression in (4.29) is the direct effect of the changing capital stock on capital cost, and thus on total average cost.

In summary, the first factor in (4.29) is the downward shift of the average variable cost curve due to R&D's technological change effect. The second factor is the shift of the average variable cost curve induced by the change in capital stock as it moves along the path leading to tangency of the short-run and long-run average cost at the minimum point of the latter, holding output fixed. The third effect is the direct impact of the variation in capital stock on total average cost. The combined effect of technological change and capital adjustment gives the total decrease in cost holding input prices fixed, namely the dual productivity growth-rate effect of R&D expenditure.

4.2.5.3) Inter-Country Differentials in the Primal and Dual Rate of Technological Change

The difference in the rates of technological change in (4.23) and (4.24) are used to assess relative efficiency or competitiveness between the U.S. and Canadian food sectors. I define, respectively, the primal and dual technological gap as the inter-country difference in the increase in output associated with R&D expenditure and the reduction in cost associated with R&D expenditure at a given point in time, ceteris paribus. The primal and dual technological gap are given by

$$\varepsilon_{YR}\,(\text{gap}) = \varepsilon_{YR,\,us} - \varepsilon_{YR,\,can} \qquad (4.30a)$$

$$\varepsilon_{CR}\,(\text{gap}) = \varepsilon_{CR,\,us} - \varepsilon_{CR,\,can} \qquad (4.30b)$$

The interpretation of (4.30a) and (4.30b) requires an additional step. Recall that the Canadian data set has been expressed in terms of U.S. dollars adjusted by a Purchasing Power Parity (PPP) index. This conversion process is essential in an international competitiveness study in order to ensure comparability of estimates. Therefore, the difference between $\varepsilon_{YR,US}$ and $\varepsilon_{YR,CAN}$ in (4.30) represents difference between the U.S. and Canada in the R&D-induced increase in output, everything else held fixed. A positive difference implies that a percentage increase in R&D increases output more in the U.S. than in Canada, ceteris paribus. In that event, the U.S. food sector has a primal technological growth advantage over Canada.

Similarly, the difference between $\varepsilon_{CR,US}$ and $\varepsilon_{CR,CAN}$ gives the inter-country difference in the total cost reduction associated with a percent increase in R&D, given that each country faced its sample mean input prices. A positive (negative) difference implies that a percentage increase in R&D results in a greater (smaller) cost reduction in U.S than in Canada. In that event, the U.S. has a dual technological growth advantage (disadvantage) over Canada.

4.2.5.4) Rates of Return to R&D

While ε_{VCR}, ε_{CR}, and ε_{YR} express the productivity effects of R&D expenditures in percentage terms, the rate of return to R&D expenditures gives the dollar cost savings generated from each dollar invested in R&D. The rate of return (RR) to R&D is given by

$$RR = -\frac{\partial VC^{total}}{\partial R} = -\frac{\partial \ln VC^{total}}{\partial \ln R} * \frac{VC^{total}}{R} = -\left(\varepsilon_{VCR}^{total} * \frac{VC^{total}}{R}\right) > 0 \qquad (4.31)$$

$\frac{\partial VC}{\partial R}$ is the negative of the decrease in variable cost associated with a dollar investment in R&D. Note that RR in (4.31) is the rate of return to R&D net of the current cost used for R&D purposes, because R&D expenditures have already been included in variable cost. In other words,

$$VC^{total} = VC^{not\ R} + R$$

Therefore,

$$RR = -\ \frac{\partial VC^{not\ R}}{\partial R} - 1 = -\frac{\partial \ln VC^{not\ R}}{\partial \ln R}\frac{VC^{not\ R}}{R} - 1$$

and

$$RR = -\ \left(\varepsilon_{VCR}{}^{not\ R}\right)\left(\frac{VC^{not\ R}}{R}\right) - 1 \qquad (4.32)$$

4.2.6 Capacity Utilization

Recall from section 3.4 that in the short run, firms may deviate from the full utilization of their resources because of exogenous shocks. In that event, capital is evaluated at its shadow price rather than at its market price and firms do not produce at the minimum point on their average cost functions. The productivity growth rate measure is affected. Excess capacity implies the firm does not minimize cost. Conversely, when a capacity shortage prevails, average cost can be reduced by investing more capital or by reducing production. From section 3.2, capacity utilization is defined as

$$CU = \frac{C^{*}}{C} = \frac{VC + \text{shadow cost}}{VC + \text{market cost}} = \frac{VC + Z_t K_t}{VC + p_t K_t} \qquad (4.33)$$

The first step toward implementing (4.33) requires computation of the elasticity of variable cost with respect to capital:

$$\varepsilon_{VCK} = \frac{\partial \ln VC}{\partial \ln K} =$$

$$\tau_K + \tau_{KK}(\ln K - \ln Y_t) + \beta_{LK}(\ln W_k - \ln W_m) + \tau_{KR}(\ln R - \ln Y_{t-s}) + \tau_{KY}(\ln Y) \quad (4.34)$$

Computation of shadow cost Z_kK_t requires additional manipulations because K is in index form (i.e. $K = K_t/K_0$). That is, the shadow price of capital is

$$Z_k = -\frac{\partial VC_t}{\partial K_t / K_{0,us}} = -\frac{\partial \ln VC_t}{\partial \ln K_t / K_{0,us}} \bullet \frac{VC_t}{K_t / K_{0,us}} = -\frac{\partial VC_t}{\partial K_t} K_{o,us} \quad (4.35)$$

Multiplying (4.35) by (K_t/K_0) gives the shadow cost of capital Z_kK_t,

$$Z_kK_t = -\frac{\partial VC_t}{\partial K_t}(K_{0,us})\left(\frac{K_t}{K_{o,us}}\right) = -\left(\frac{\partial VC_t}{\partial K_t}\right)K_t \quad (4.36)$$

Similarly, the market price of capital weighted by the base-year quantity in the base country is

$$p_tK_{o,us} = \left(\frac{W_t}{W_{0,us}}\right)(W_{o,us}K_{o,us}) \quad (4.37)$$

Multiplying (4.37) by (K_t/K_0) gives the market cost of capital p_tK_t,

$$(p_t\, K_{o,us})\,(K_t/K_{o,us}) = p_tK_t \quad (4.38)$$

4.2.7 Factor Demand Elasticities and Curvature Checks

The computation of factor demand elasticities provides additional information on the characteristics underlying the production structures of the U.S. and Canadian food processing sectors. Using the translog parameter estimates, own-price elasticities of labor and materials at the sample-mean expansion point are (Antle and Capalbo, 1988):

$$\varepsilon_{LL} = (\gamma_{LL} + \beta_L^2 - \beta_L) / \beta_L < 0$$
$$\varepsilon_{MM} = (\gamma_{MM} + \beta_M^2 - \beta_M) / \beta_M < 0 \qquad (4.39)$$

The cross-price elasticities between material and labor at the sample mean are given by

$$\varepsilon_{LM} = (\gamma_{LM} + \beta_L\beta_M) / \beta_L$$
$$\varepsilon_{ML} = (\gamma_{LM} + \beta_L\beta_M) / \beta_M \qquad (4.40)$$

The own-price elasticities in (4.39) give the percentage change in the demand for input i as a response to its own price increase. On the other hand, the cross-price elasticities in (4.40) indicate the percentage variation in demanded input i while the price of input j rises by one percent. The latter indicate substitution possibilities among factors of production. Using (4.39) and (4.40), the Allen-Uzawa elasticities can be computed as

$$\sigma^A_{LL} = \varepsilon_{LL} / \beta_L \text{ and } \sigma^A_{MM} = \varepsilon_{MM} / \beta_M$$
$$\sigma^A_{LM} = \varepsilon_{LM} / \beta_M \text{ and } \sigma^A_{ML} = \varepsilon_{LM} / \beta_L \qquad (4.41)$$

Finally, the Morishima substitution elasticities between labor and materials are given by

$$\sigma^M_{LM} = \varepsilon_{ML} - \varepsilon_{LL}$$
$$\sigma^M_{ML} = \varepsilon_{LM} - \varepsilon_{MM} \qquad (4.42)$$

σ^M_{LM} gives the percentage variation in the ratio of labor to material quantity (L/M) caused by a percentage change in the labor-to-material price ratio (W_l/W_m) induced by a change in W_l. According to Chambers (1988), the Morishima substitution elasticity is preferred to the Allen elasticity because the Morishima is an effective measure of the shape of the labor-material isoquant. Given that only two inputs are included in the variable cost function, the two elasticities in (4.42) equal one another.

In order to be a valid representation of the technology, the estimated model must meet the regularity conditions presented in section 4.2.1. Recall that symmetry and homogeneity properties are already met, since restrictions (4.7) and (4.8) were imposed in the system of equations. The properties of monotonicity, concavity in input prices, and convexity with respect to output, capital, and R&D, remain to be tested. All the tests are conducted at the point of approximation.

Following Antle and Capalbo (1988), monotonicity in input prices requires the cost share to be positive. In other words, the fitted share of labor and materials in (4.9) must be greater than zero. At the sample mean, monotonicity in input prices is ensured if

$$\beta_L > 0 \text{ and } \beta_M > 0 \tag{4.43}$$

Similarly, monotonicity in output requires that the fitted value of $\frac{\partial \ln VC}{\partial \ln Y}$ in (4.10) be greater than zero. At the sample mean, the variable cost function is not decreasing in output if

$$\theta_Y - \tau_K > 0 \tag{4.44}$$

Finally, monotonicity in the fixed input is maintained if the fitted value of $\frac{\partial \ln VC}{\partial \ln K}$ in (4.34) and $\frac{\partial \ln VC}{\partial \ln R}$ in (4.22) are less than zero. Therefore at the sample mean, the cost function will be decreasing in capital and R&D if

$$\tau_K < 0$$
$$\lambda_R < 0 \tag{4.45}$$

The necessary and sufficient conditions for concavity in input prices requires the Hessian matrix of second partial derivatives of variable cost with respect to factor prices be negative semi-definite. In order words, the determinants of the principal minors of the estimated Hessian should alternate in sign, beginning with a negative. Using the σ^A_{ij} matrix, (the Allen-Uzawa elasticities as defined in 4.41), namely

$$\begin{vmatrix} \sigma^A_{LL} & \sigma^A_{LM} \\ \sigma^A_{ML} & \sigma^A_{MM} \end{vmatrix},$$

the necessary and sufficient conditions for quasi-concavity of the variable cost function in input prices are (Antle and Capalbo, 1988; Berndt, 1991):

$$\sigma_{LL} < 0 \quad \text{and} \quad (\sigma_{LL}\sigma_{MM} - \sigma_{ML}\sigma_{LM}) \geq 0. \tag{4.46}$$

Convexity with respect to output quantity, capital, and R&D require the Hessian matrix of second partial derivatives of cost with respect to Y, K, and R be positive semi-definite. Following Hazilla and Kopp (1986), the necessary and sufficient conditions for quasi-convexity of the variable cost function in K and R are, respectively,

$$\begin{aligned} &\tau_K < 0 \quad \text{and } \tau_{KK} - \tau_K^2 - \tau_K > 0 \\ &\lambda_R < 0 \text{ and } \lambda_{KK} - \lambda_K^2 - \lambda_K > 0 \end{aligned} \tag{4.47}$$

4.2.8) Procedures

I will first estimate the three-equations model described in section 4.2.3, using annual data from 1962 to 1993 in the U.S. and 1963 to 1992 in Canada. Next, I will conduct hypothesis tests on the parameters restrictions derived in section 4.2.4, using the log likelihood ratio. Results of the statistical inference will provide information on the technology underlying the U.S. and Canadian food sectors. If homotheticity, homogeneity, or constant returns to scale cannot be rejected in either country, I will impose the appropriate set of restrictions on the model. Then, I will proceed to the curvature checks and to computation of factor demand elasticities. Finally, I will estimate and analyze the productivity indicators associated with R&D expenditures, as derived in section 4.2.5, and compute capacity utilization in the U.S. and Canadian food sectors.

The remaining issue to be considered before proceeding to estimation is the choice of a lag period. As the literature provides little guidance on the choice of an appropriate lag, I will perform several sets of regressions along with different time lags. Choice of optimal lag will be based on theoretical consistency of estimates at the point of approximation. Ideally, the length of lag should be the same for the U.S. and Canada in order to provide comparable models. Availability of historical data on R&D and output impose, however, some limit on the length of lag that can be implemented in our model. Indeed, the earliest year for which R&D and output data are available for the U.S. are, respectively, 1958 and 1949. In Canada, the R&D data set begins in 1955 but the earliest year of data available for output data is 1961. I therefore limit the testing procedure to zero to six years in the U.S. and to zero to three years in Canada.

Chapter 5: Results

5.1 Initial Results

Initial results obtained from estimating our system of equations were overall disappointing. The regularity conditions were violated at the point of approximation regardless of the length of the lag period imposed. Compliance of the estimated parameters to the theoretical properties is required to ensure that the translog variable cost function is a valid representation of the technology. Furthermore, the magnitudes of several second-order parameters were implausible in both the U.S. and Canadian models. For instance in the U.S., the point estimate for the output second-order parameter (θ_{YY}) was -1.84, indicating not only that there is an inverse U-shaped average cost curve, but that an increase in output of 1% would reduce the elasticity of cost with respect to output by 184 percentage points! In Canada, the slope coefficient for R&D (λ_R) was positive at the point of approximation, violating the monotonicity requirement. As λ_R is a crucial parameter in estimating productivity, a positive sign would preclude us from computing plausible estimates of productivity growth.

For several reasons, we concluded that these poor estimates stemmed from multicollinearity in the data. First, the output, capital, and R&D data trend upward over time and show only modest variation, making it difficult to isolate the separate effect of each variable in the statistical model. Second, estimates were sensitive to slight alterations in the sample period or to deletion of nonsignificant variables. Third, a look at the correlation matrix indicated strong linear association (correlation coefficient above 0.80) between labor price and output in both the U.S. and Canada, as well as between output and capital per unit of output in the U.S. The resulting implausible results did not merit further analysis and could not be used to assess productivity.

Several authors have reported multicollinearity problems in using a translog functional form with aggregate data. For instance, Antle and Capalbo (1988), in their comparison of translog econometric models of production in the U.S. agricultural sector, reported multicollinearity and violation of the curvatures conditions. Bernstein and Nadiri (1978) used a truncated translog variable cost function (i.e. all second-order parameters were restricted to zero) because they were unable to find parameter estimates which satisfied the regularity conditions. Stevenson (1980, p.166, footnote 4) noted that an increase in the number of explanatory variables in the translog is likely to lead to a high degree of multicollinearity.

A solution is to use nonsample information in the form of linear restrictions on the parameters (Griffiths, Hill, Judge 1993). We therefore proceeded by imposing parameter restrictions, beginning with homotheticity, homogeneity, and finally constant returns to scale along with alternative time lags. The choice of the preferred model was based not on statistical inference but rather on the following criteria:

1. compliance with theoretical properties of a variable cost function (monotonicity and curvature conditions);[13]
2. magnitudes and signs of parameters;
3. trends in the various indicators of productivity. (6.1)

5.2 Homothetic and Homogeneous Model Results in the U.S.

In the U.S., estimated parameters from the homothetic model violated convexity in capital, output, and R&D regardless of the length of the lag period chosen. In addition, magnitudes of several second-order parameters were implausible. Concavity in input prices as well as monotonicity in slope parameters tended to be satisfied. Imposing homogeneity satisfied all curvature requirements at the point of approximation and reduced the size of the second-order coefficients. However, except for the one-year lag model, the slope parameter of the R&D variable (λ_R) was nonsignificant and decreased in

[13] Recall that monotonicity implies that variable cost is non-decreasing in input prices and output, and non-increasing in R&D and in capital. At the point of approximation, all monotonicity requires is non-negativity in the slope parameters of input prices and output, and non-positivity in the slope parameters of R&D and capital.

magnitude as the length of the lag increased, becoming positive in the three-year to six-year lag models. Finally, some parameters were sensitive to the choice of the lag implemented.

In Canada, all curvature requirements were satisfied when homotheticity was imposed. However, the slope coefficient for R&D was not statistically significant and was very small in magnitude. In the one-year lag model, the non-positivity requirement in R&D expenditure was violated. When the parameters were restricted for homogeneity, estimates satisfied all curvature conditions except for convexity in the fixed input. The sign on the capital quantity's slope coefficient was positive, violating monotonicity. Estimates were, however, very stable regardless of the length of lag.

5.3 Final Model

On the basis of the regression results described above and the criteria defined in (5.1), I imposed long-run constant returns to scale (LRCRTS) to ensure theoretically valid estimates of the variable cost function at the point of approximation. Although LRCRTS was rejected via the log likelihood ratio test, estimates were robust and in line with the criteria defined in (5.1). In addition, at the aggregate level, LRCRTS is justifiable: economies or diseconomies of scale might be found in some of the individual industries composing the food sector, but ought on average to be zero at the aggregate level.

Overall, the best-performing lag length was two years. One may criticize the shortness of this lag, but as the R&D data include only current expenditures, their effect might plausibly take place within a short time period. We note that Wagner (1968) calculated a total lag of 2.17 years in the non-durable manufacturing industries (reported by Pakes and Schankerman, 1984).

5.4 Estimates and Curvature Checks

Parameter estimates, log likelihood statistics, and goodnesses of fit are presented in tables 5.1a and 5.1b. We first note the strong fit of the variable cost equation in both countries, implying that over 90% of the variability in cost are explained by the variable cost equation. The share equation, however, fits the data better in Canada than in the U.S., having an R^2 of 0.52 in Canada compared with 0.14 in the U.S. In both countries, the output equation fits the data poorly.

Turning to curvature checks, the estimated parameters for the U.S. food sector satisfy all the regularity conditions at the point of approximation. Monotonicity is also satisfied for all inputs, output, and R&D expenditure. In Canada, except for convexity in the fixed factor, all curvature conditions are satisfied.

Serial correlation in the residuals was detected in both countries and was not rejected at the five percent significance level. A first-order AR1 specification scheme was attempted in each equation, following Berndt and Savin (1978). After correction, the estimated slope coefficient for R&D became positive and non-significant in both the U.S. and Canada, violating monotonicity and precluding us from computing plausible productivity indicators. For this reason, the non-corrected model was chosen as the preferred one, keeping in mind that the true significance levels of hypothesis tests are affected by serial correlation. The interested reader can find the results of the AR1 model in the annex.

On the basis of equation (4.22), estimates in tables 5.1a and 5.1b provide information on the structure of technological change in the U.S. and Canadian food sectors. Coefficient β_{LR} indicates the effect of a percentage increase in R&D expenditure on the share of labor; in other words, it measures the bias of technological change induced by R&D (see section 3.3.1). Our estimates suggest that technological change is labor-saving in both the U.S. and Canada. A one percent increase in R&D expenditure induces a 0.06% decrease in the share of labor in the U.S. and a 0.03% decrease in Canada. Although statistically nonsignificant, these results were robust to changes in specification. In Canada, for example, regardless of the lag length and parameter restrictions, β_{LR} ranged only from -0.02 to -0.04. In the U.S, β_{LR} ranged from -0.02 to -0.04 in the homothetic model and from -0.06 to -0.08 in the constant-returns-to-scale model regardless of lag length. Our finding is also consistent with Jorgenson and Fraumeni (1981), who reported that technological change is labor-saving in the food sector. Antle and Capalbo (1988) found that technological change decreases the share of labor by 0.05% to 0.06% in the U.S. agricultural sector. Multicollinearity, then, seems to be the cause of the low significance level on β_{LR}.

Parameter λ_{RR} indicates the rate of change of the percentage reduction of variable cost associated with a one percent increase in R&D expenditure. In both the U.S. and Canada, this coefficient is negative, implying that a one-percent increase in R&D accelerates the R&D-induced rate of reduction of variable cost. However, the sensitivity of the λ_{RR} parameter to alternative specifications casts some doubt on the reliability of our estimate.

Finally, τ_{KR} indicates the effect of a percentage increase in the stock of capital on the rate of reduction of variable cost associated with R&D expenditure. Regardless of the length of lag, τ_{KR} varies from -0.5 to -0.10 in all Canadian model specifications, and from 0.03 to 0.05 in the U.S. LRCRTS model. These results imply that increasing capital input shifts the average variable cost curve at an increasing rate in Canada but at a decreasing rate in the United States.

Table 5.1a: Translog Variable Cost Function Estimate, United States

Parameter	Variable	Estimate	T-Statistic
α_0	Constant	5.53	196.49
β_L	$(\ln W_l - \ln W_m)$	0.26	22.83
γ_{LL}	$0.5\,(\ln W_l - \ln W_m)^2$	0.16	1.42
λ_R	$(\ln R_{t-s} - \ln Y_{t-s})$	-0.27	-1.66
β_{LR}	$(\ln W_l - \ln W_m)(\ln R_{t-s} - \ln Y_{t-s})$	-0.06	-0.80
λ_{RR}	$0.5\,(\ln R_{t-s} - \ln Y_{t-s})^2$	-0.19	-0.35
τ_K	$(\ln K - \ln Y_t)$	-0.34	-28.50
β_{LK}	$(\ln W_k - \ln W_m)(\ln K - \ln Y_t)$	-0.06	-0.71
τ_{KK}	$0.5\tau_{KK}\,(\ln K - \ln Y_t)^2$	-0.21	-1.40
τ_{KR}	$(\ln K - \ln Y)(\ln R_{t-s} - \ln Y_{t-s})$	0.03	0.49
Equation			**R^2**
Variable cost			0.96
Share of labor			0.14
Output price			0.02
Log of likelihood function			**224.85**

Table 5.1b: Translog Variable Cost Function Estimate, Canada

Parameter	Variable	Estimates	T-Statistic
α_0	Constant	3.35	115.19
β_L	$(\ln W_l - \ln W_m)$	0.31	56.34
γ_{LL}	$0.5\,(\ln W_l - \ln W_m)^2$	0.12	4.87
λ_R	$(\ln R_{t-s} - \ln Y_{t-s})$	-0.21	-1.44
β_{LR}	$(\ln W_l - \ln W_m)(\ln R_{t-s} - \ln Y_{t-s})$	-0.03	-0.68
λ_{RR}	$0.5\,(\ln R_{t-s} - \ln Y_{t-s})^2$	-0.12	-0.69
τ_K	$(\ln K - \ln Y_t)$	-0.08	-3.35
β_{LK}	$(\ln W_k - \ln W_m)(\ln K - \ln Y_t)$	-0.27 E-02	-0.06
τ_{KK}	$0.5\tau_{KK}(\ln K - \ln Y_t)^2$	-0.19	-1.75
τ_{KR}	$(\ln K - \ln Y)(\ln R_{t-s} - \ln Y_{t-s})$	-0.07	-0.81
Equation			**R^2**
Variable cost			0.93
Share of labor			0.52
Output price			0.09
Log of likelihood function			**234.50**

5.5 Elasticities

Tables 5.2a and 5.2b present the corresponding estimates of factor demand elasticities and Morishima substitution elasticities in the U.S. and Canadian food sectors. These elasticities were computed at the point of approximation. Overall, the results show that:

1. In both countries, the own-factor price elasticities indicate that labor and materials are price inelastic, the greater inelasticity being in materials;
2. In both countries, materials and labor are poor substitutes for one another, given a fixed capital stock;
3. All elasticities are greater in absolute value in Canada than in the United States, implying that the Canadian food sector is more responsive to changes in factor prices than is the U.S. food sector.

Specifically, the demand for labor decreases by 1.4% in the U.S. and by 3.0% in Canada in response to a ten percent increase in the labor wage. Similarly, the demand for materials decreases by 0.5% in the U.S. and by 1.4% in Canada when material prices rise by ten percent. Turning to the estimates of cross-price elasticities, we note that the demand for labor is more sensitive to a change in material price than the demand for materials is to a change in the labor wage. Indeed, a ten percent increase in the price of materials raises the demand for labor by 1.4% in the U.S. and by 3.0% in Canada. In contrast, the demand for materials increases by only 0.5 % in the U.S. and by 1.4% in Canada in response to a ten percent increase in the price of labor. Observe that the elasticity matrices are symmetric in any two-variable input model because of the linear homogeneity restrictions in input prices.

The Morishima substitution elasticities also indicate greater substitutability between labor and materials in Canada than in the United States: a ten percent increase in the ratio of labor wage to material price increases the use of labor relative to materials by 2.0% in the U.S. and by 4.4% in Canada. The higher substitution elasticity in Canada can be attributed to the fact that the more capital-intensive a technology is, the less flexible is the capital in the sense of permitting variations in combinations of labor and materials. In terms of ratio of capital to labor, the U.S. food sector is more capital intensive than the Canadian food sector (average K/L ratio of 0.73 in the U.S. compared with 0.53 in Canada).[14]

Table 5.3 compares our elasticity estimates for the U.S. with those in Goodwin and Brester (1995). Goodwin and Brester reported elasticities for each of two periods in order to analyze the effect of structural change in the early 1980's. We first note that the own-price elasticities estimated in the present study are much lower than those in Goodwin and Brester (1995). For instance, Goodwin and Brester's estimates of own-price elasticities of labor were -0.77 and -0.47 in the first and second period, respectively, while we find the elasticity to be -0.14 at the point of approximation. The cross-price elasticity of labor demand with respect to material prices estimated in the present study (0.14) is, however, somewhat closer to the one obtained by Goodwin and Brester (0.28 and 0.067 in the first and second period, respectively). The fairly low responsiveness found here in material demand to a labor wage change (0.052) is consistent with Goodwin and Brester's finding (0.06 in the first regime, i.e. between 1972-80). Finally, our estimated Morishima substitution elasticities are lower than the ones obtained by Goodwin and Brester (1995).

The lower substitution elasticities in my model may be explained by the fact that I use a partial equilibrium model in which capital is held fixed. With a fixed capital configuration, substitution possibilities between the remaining variable inputs are limited. Goodwin and Brester, in contrast, used a full equilibrium model in which all productive factors adjust instantaneously to exogenous changes. This confirms, therefore, Le Chatelier proposition, namely that long-run own-price elasticities of demand are larger in absolute value than are the corresponding short-run elasticities. Unfortunately, to our knowledge, no comparable study is available for Canada besides the present one.

[14] Computed from the KLEMS data set provided by BLS and Statistics Canada.

Table 5.2a: Factor Demand Elasticities in the U.S. Food Sector

FACTOR DEMAND ELASTICITIES	Quantities	Prices	
		LABOR	MATERIALS
Own and Cross Price Elasticity	LABOR	-0.14487	0.14487
	MATERIALS	0.052054	-0.052054
Morishima Substitution Elasticity	LABOR		0.19692
	MATERIALS	0.19692	

Note: Factor demand elasticities are computed from equations (4.39) and (4.40). Morishima substitution elasticities are computed from equation (4.42).

Table 5.2b: Factor Demand Elasticities in the Canadian Food Sector

FACTOR DEMAND ELASTICITIES	Quantities	Prices	
		LABOR	MATERIALS
Own and Cross Price Elasticity	LABOR	-0.30754	0.30754
	MATERIALS	0.13976	-0.13976
Morishima Substitution Elasticity	LABOR		0.44730
	MATERIALS	0.44730	

Note: Factor demand elasticities are computed from equations (4.39) and (4.40). Morishima substitution elasticities are computed from equation (4.42).

Table 5.3: Factor Demand Elasticities in the U.S. Food Sector, Goodwin and Brester

FACTOR DEMAND ELASTICITIES			
		PRICES	
PERIODS	QUANTITIES	LABOR	MATERIALS
First period	LABOR	-0.771	0.286
Second period		-0.474	0.067
First period	MATERIALS	0.065	-0.293
Second period		0.015	-0.666
MORISHIMA SUBSTITUTION ELASTICITIES			
		PRICES	
PERIODS	QUANTITIES	LABOR	MATERIALS
First period	LABOR		0.837
Second period			0.490
First period	MATERIALS	0.580	
Second period		0.733	

Source: Goodwin, B.K. and G.W.Brester (1995), " Structural Change in Factor Demand Relationships in the U.S. Food and Kindred Products Industry," *American Journal of Agricultural Economics,* 77: 69-79.

5.6 Results: Trends in R&D Primal and Dual Rates of Technological Change

Tables 5.4a and 5.4b provide estimates of technological change associated with R&D expenditure (defined in section 4.2.5) in the U.S. and Canadian food sectors from the early 1960s to early 1990s. The first two columns present the dual technological change effect of R&D, that is the effect of R&D on variable and total cost when capital is held fixed. The third column is a measure of R&D's primal technological change effect, namely the percentage increase in output resulting from a one-percent increase in R&D.

Although an estimate in any given year is interesting, trends in the estimates provide a better indicator of the performance of each country's food sector. R&D expenditures create process innovations, which in turn decrease cost or increase output quantity or value, ceteris paribus. The rate at which R&D-induced cost reduction or output growth changes over time provides an indication of the dynamic performance of each country's food sector. A rising trend indicates that innovations brought about by R&D expenditure are, in percentage terms, rising over time, while a declining trend implies they are falling. It is important to keep in mind that a decreasing trend does not imply negative productivity growth! It only refers to a reduced rate at which R&D-induced technical and productivity change occurs. A look at these rates can thus be used to identify cycles or trends in R&D performance.

It is useful to consider the average proportionate rates of ε_{CR} and ε_{YR} over selected time periods, as reported in table 5.5. Figures (5.1) and (5.2) also help to visualize the trends in these key indicators. A look at the graphs reveals plausible trends in the productivity and technological change effects of R&D expenditures. This is reassuring and suggests that we have a representative model of food processing technology despite multicollinearity and some evidence of serial correlation.

Table 5.5 reveals that, in the U.S., the proportionate reduction in short-run total cost (SRTC) resulting from a one-percent increase in R&D (i.e. ε_{CR}) rises between 1962 and 1972, averaging an annual proportionate rate of 3.85%. The opposite trend is observed during the 1973-82 period, which coincides with a general slowdown in the U.S. economy. From table 5.4a, a one-percent increase in R&D decreased cost by 0.24% in

1973, while in 1982 it decreased cost by only 0.20%. The next sub-period, covering 1983 to 1988, is characterized by a sharp increase in the technical effect of R&D, during which time the average percentage growth in ε_{CR} was 8.04% per year (see table 5.5). After 1988, however, the estimates show a declining trend in the cost reduction associated with R&D expenditures.

On the primal side, ε_{YR} gives the percentage increase in output caused by a one-percent increase in R&D expenditure. Similar trends are noted: an increasing rate of output growth associated with R&D characterized the 1962-72 period. This was followed by a declining rate over the 1972-82 period. From 1982 to 1988, figure 5.1b reveals a sharp increase in the rate of output associated with R&D. After 1988, a declining trend is observed.

In summary, the sharpest increase in R&D's technical impact occurs during the 1983-88 period, when the U.S. economy was recovering from recession and the restructuring taking place in U.S. manufacturing was having its effect.[15] In that same period, growth in shipment value was also at its greatest, as discussed in chapter two.

Turning to the Canadian food sector, figure 5.2a and table 5.5 reveal a sharp increase, from 1963 to 1974, in the rate of reduction in short-run total cost associated with R&D (i.e. ε_{CR}). The rate averaged 11.72% per year during this period. From 1975 to 1981, however, an opposite trend is observed: cost decreases associated with R&D averaged - 2.43% per year. After 1982, three patterns can be identified from figure 5.2a: a sharp increase in the rate of cost reduction from 1982 to 1984, followed by a downward trend until 1987, and finally an increasing rate from 1988 to 1992. The primal rates of technological change exhibit a similar pattern.

From table 5.5, we note that the timing and magnitude at which these trends occur differ between the two countries. For instance in the U.S., the decline in the technical and productivity effects of R&D coincide with the first oil crisis in 1973, while in Canada the decline begins only in 1975. In addition, the period of productivity slowdown was shorter in Canada than in the U.S., implying that the effect of the post-1973 recession was more

[15] Examples are tax incentives to stimulate investment, and anti-trust laws. Also, a great deal of merger activity occurred from the early to mid-80's.

severe in the U.S. than in Canada. However, after 1982, the U.S. food sector outperformed Canada in terms of both the rate of cost decreases and output increase associated with R&D. The latter result implies that the U.S. food sector recovered faster and stronger than did Canada from the 1982 recession. These findings are consistent with the comparative trends in shipment value observed in chapter two. The post-1989 results show secularly decreasing proportionate effects of R&D expenditures in the U.S. but secularly increasing effects in Canada.

Table 5.4a: Estimates of the Primal and Dual Rates of Technological Change Induced by R&D Expenditure in the U.S. Food Sector

YEAR	ε_{VCR}	ε_{CR}	ε_{YR}
1962	-0.180	-0.166	0.136
1963	-0.196	-0.179	0.148
1964	-0.217	-0.198	0.164
1965	-0.226	-0.208	0.172
1966	-0.227	-0.207	0.172
1967	-0.242	-0.222	0.183
1968	-0.250	-0.229	0.189
1969	-0.257	-0.236	0.195
1970	-0.256	-0.235	0.194
1971	-0.259	-0.237	0.195
1972	-0.269	-0.250	0.204
1973	-0.258	-0.243	0.195
1974	-0.262	-0.248	0.198
1975	-0.254	-0.230	0.190
1976	-0.241	-0.222	0.180
1977	-0.250	-0.230	0.186
1978	-0.232	-0.216	0.173
1979	-0.236	-0.221	0.175
1980	-0.233	-0.218	0.173
1981	-0.229	-0.212	0.169
1982	-0.225	-0.205	0.166
1983	-0.245	-0.223	0.180
1984	-0.277	-0.249	0.205
1985	-0.291	-0.261	0.215
1986	-0.336	-0.301	0.249
1987	-0.339	-0.301	0.251
1988	-0.364	-0.324	0.271
1989	-0.342	-0.303	0.254
1990	-0.324	-0.282	0.239
1991	-0.324	-0.283	0.238
1992	-0.318	-0.278	0.232
1993	-0.321	-0.283	0.233

Note: ε_{VCR}, ε_{CR}, and ε_{YR} are respectively computed from equations (4.22), (4.24), and (4.23) in chapter 4.

Figure 5.1a: Cost Reduction Induced by R&D Expenditure in the U.S. Food Sector

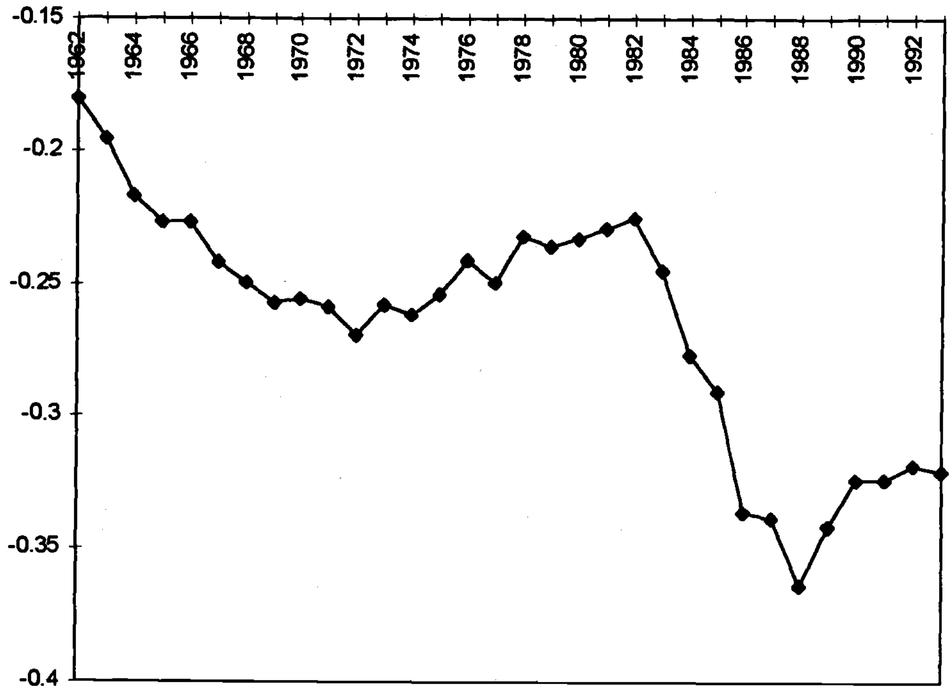


Figure 5.1b: Output Increases Induced by R&D Expenditure in the U.S. Food Sector

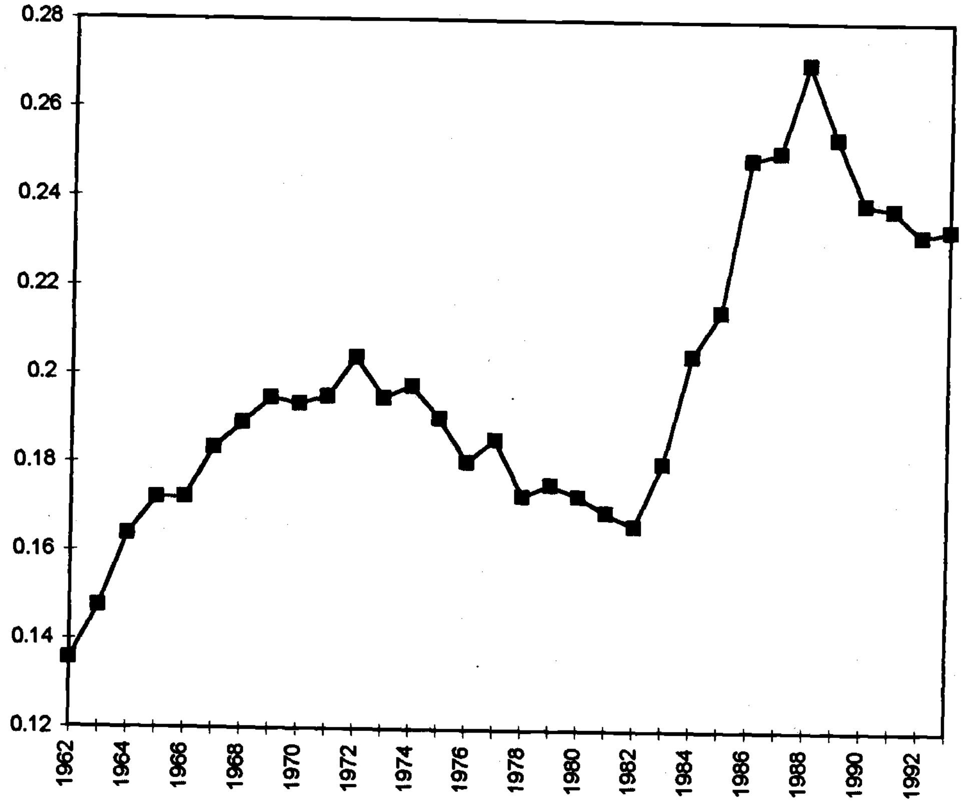


Table 5.4b: Estimates of the Primal and Dual Rates of Technological Change Induced by R&D in the Canadian Food Sector

YEAR	ε_{VCR}	ε_{CR}	ε_{YR}
1963	-0.075	-0.067	0.074
1964	-0.111	-0.098	0.108
1965	-0.140	-0.125	0.135
1966	-0.156	-0.139	0.149
1967	-0.186	-0.164	0.174
1968	-0.223	-0.199	0.204
1969	-0.206	-0.185	0.190
1970	-0.216	-0.194	0.198
1971	-0.219	-0.196	0.200
1972	-0.227	-0.201	0.207
1973	-0.218	-0.193	0.200
1974	-0.230	-0.207	0.210
1975	-0.207	-0.186	0.191
1976	-0.209	-0.186	0.195
1977	-0.212	-0.189	0.199
1978	-0.211	-0.189	0.198
1979	-0.190	-0.170	0.180
1980	-0.192	-0.175	0.182
1981	-0.192	-0.173	0.181
1982	-0.205	-0.183	0.192
1983	-0.207	-0.182	0.193
1984	-0.230	-0.201	0.212
1985	-0.226	-0.195	0.209
1986	-0.214	-0.185	0.200
1987	-0.212	-0.182	0.199
1988	-0.224	-0.193	0.207
1989	-0.229	-0.197	0.210
1990	-0.238	-0.201	0.217
1991	-0.235	-0.194	0.213
1992	-0.240	-0.198	0.218

Note: ε_{VCR}, ε_{CR}, and ε_{YR} are respectively computed from equations (4.22), (4.24), and (4.23) in chapter 4.

Figure 5.2a: Cost Reduction Induced by R&D Expenditure in the Canadian Food Sector

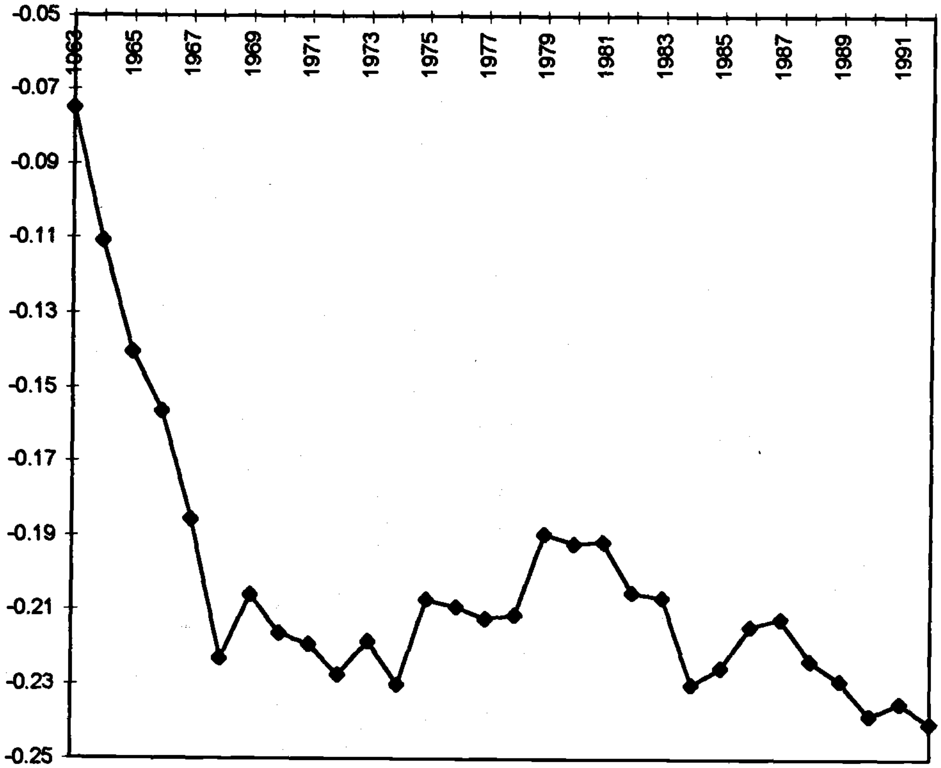


Figure 5.2b: Output Increases Induced by R&D Expenditure in the Canadian Food Sector

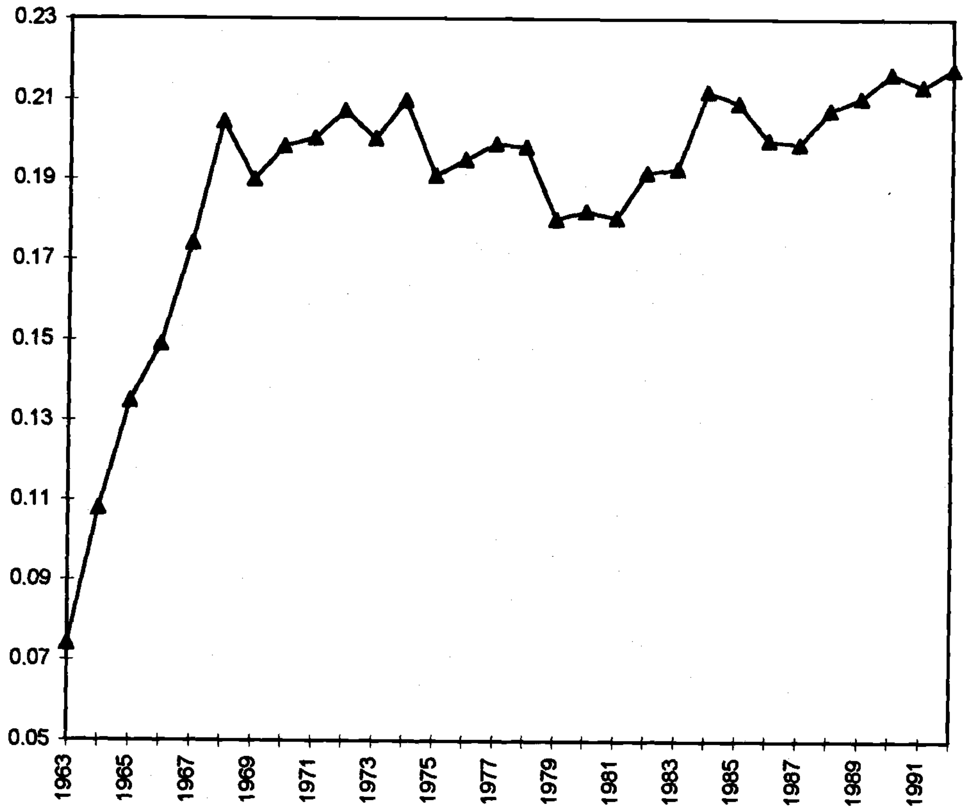


Table 5.5: Percentage Impact on Output and Cost of One Percent Increase in R&D Expenditure, U.S. and Canada, Selected Periods

U.S.			Canada		
Period	ε_{YR}	ε_{CR}	Period	ε_{YR}	ε_{CR}
1962-72	3.72	3.85	1963-74	10.78	11.72
1973-82	-1.98	-1.89	1975-81	-2.01	-2.43
1983-88	8.58	8.04	1982-87	2.19	1.58
1989-93	-3.74	-3.74	1988-92	1.83	1.68

5.7 Differences Between U.S and Canadian Primal and Dual Rates of Technological Growth

Differences in the primal and dual rates of technological growth (defined in section 4.2.5.3) indicate the relative performance of the U.S. and Canadian food sectors in terms of output increases and cost reductions induced by R&D expenditure, everything else held constant.

Figure 5.3 reveals a wide difference in the primal rate of technological change in Canada in the early 1960's in favor of the U.S. However, the gap narrows and eventually converges in the late 1960's. From 1970 to 1984, both countries show very similar patterns, implying that the effectiveness of each country's R&D to increase output is approximately the same, with a slight advantage to Canada. The year 1984 was, however, a point of departure for a widening R&D technological advantage to the U.S. food sector. In 1988, the inter-country difference in technology growth rate reached a peak. Given each country input prices, output, and capital in that year, the increase in output induced by an increase in R&D would have been six percentage points higher in the U.S. than in Canada. After 1988, this efficiency advantage over Canada decreased again.

Inter-country differences in the dual rate of technological change express the differences between these two countries in the rate of cost reduction rather than output increase. My estimates of such dual technology gaps are reported in table 5.7 and illustrated in figure 5.4. The results reveal a pattern different from the inter-country difference in output growth discussed above. Over the sample period, the U.S. had a net advantage over Canada in the cost reduction resulting from R&D growth. A closer look at the results reveals that the U.S's cost reduction advantage over Canada decreased between 1963 to 1982, increased rapidly between 1983 to 1988, and decreased again after 1988.

In summary, these figures reveal that the percentage reduction in cost associated with R&D is greater in the United States than in Canada over the entire sample period, implying, in the dual rate a technological growth advantage in the U.S. On the other hand, the U.S. advantage in terms of output increases associated with R&D expenditure, namely the primal, is not so obvious. Indeed, from 1970 to 1984, the inter-country output growth difference is very small, with a slight advantage to Canada.

Capacity utilization in the United States and Canada are discussed in the next section. We will see if the patterns discussed above can be explained through inter-country differences in capacity utilization.

Table 5.6: Primal Rate of Technological Change Differential Between the U.S. and Canada

YEAR	$\varepsilon_{YR,US}$	$\varepsilon_{YR,CAN}$	$\varepsilon_{YR,US} - \varepsilon_{YR,CAN}$
1963	0.148	0.074	0.074
1964	0.164	0.108	0.056
1965	0.172	0.135	0.037
1966	0.172	0.149	0.023
1967	0.184	0.174	0.010
1968	0.189	0.204	-0.015
1969	0.195	0.190	0.005
1970	0.194	0.198	-0.005
1971	0.195	0.200	-0.005
1972	0.204	0.207	-0.003
1973	0.195	0.200	-0.005
1974	0.198	0.210	-0.012
1975	0.190	0.191	0.000
1976	0.181	0.195	-0.014
1977	0.186	0.199	-0.013
1978	0.173	0.198	-0.025
1979	0.176	0.180	-0.005
1980	0.173	0.182	-0.009
1981	0.169	0.181	-0.011
1982	0.166	0.192	-0.026
1983	0.181	0.193	-0.012
1984	0.205	0.212	-0.007
1985	0.215	0.209	0.006
1986	0.249	0.200	0.049
1987	0.251	0.199	0.052
1988	0.271	0.207	0.063
1989	0.254	0.210	0.043
1990	0.239	0.217	0.023
1991	0.238	0.213	0.025
1992	0.232	0.218	0.014

Note: ε_{YR} is computed from equation (4.23): It reflects the percent change in output associated with a one percent increase in R&D expenditures.
The inter-country difference in the primal rate of technological change is computed following (4.30a.)

Figure 5.3: Difference in the Primal Rate of Technological Change Between the U.S. and Canadian Food Sectors

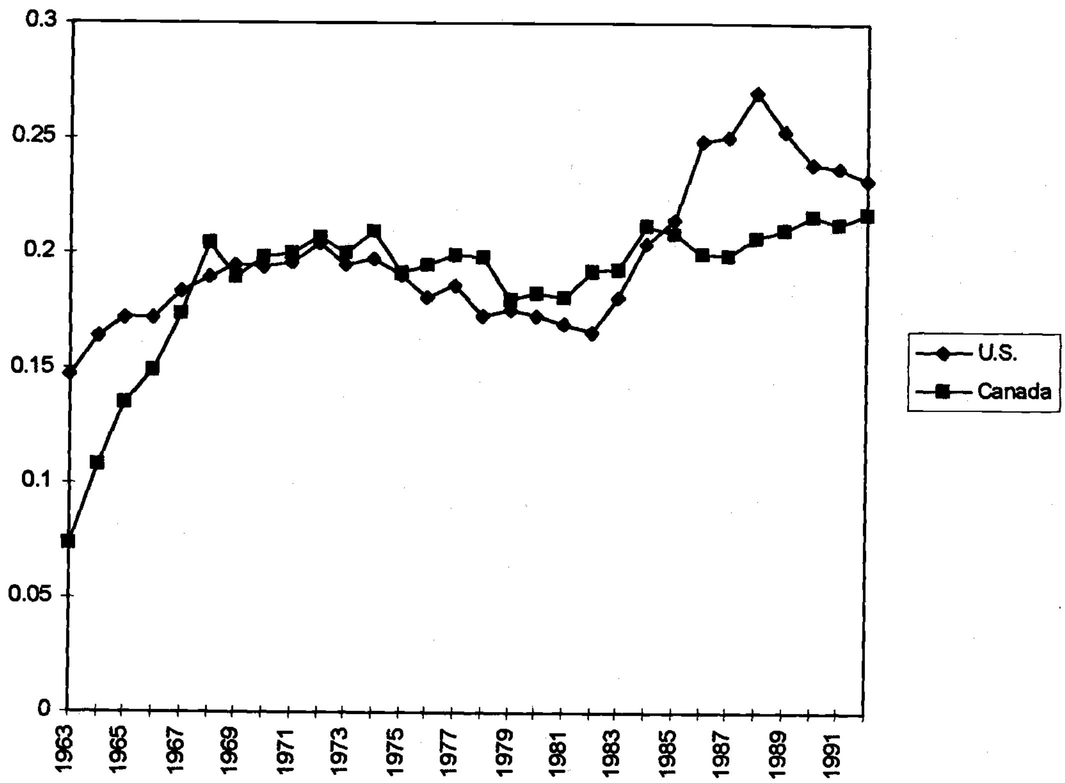
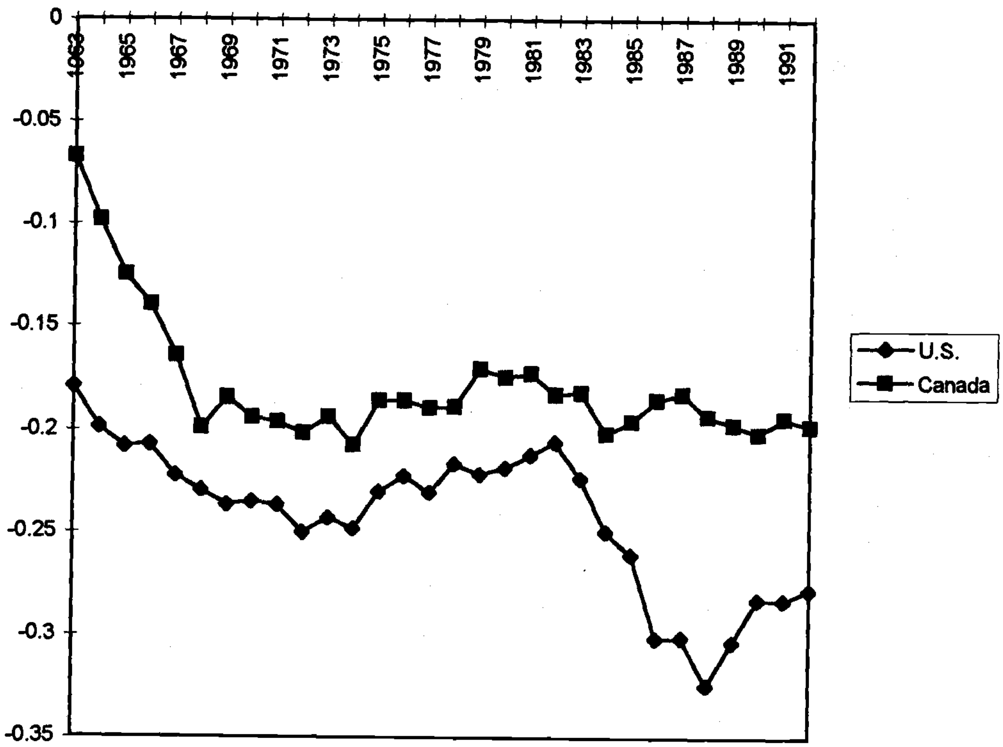


Table 5.7: Dual Rate of Technological Change Differential Between the U.S. and Canada

YEAR	$\varepsilon_{CR,US}$	$\varepsilon_{CR,CAN}$	$\varepsilon_{CR,US} - \varepsilon_{CR,CAN}$
1963	-0.179	-0.067	-0.112
1964	-0.198	-0.098	-0.100
1965	-0.208	-0.125	-0.083
1966	-0.207	-0.139	-0.068
1967	-0.222	-0.164	-0.057
1968	-0.229	-0.199	-0.030
1969	-0.236	-0.185	-0.052
1970	-0.235	-0.194	-0.041
1971	-0.237	-0.196	-0.041
1972	-0.250	-0.201	-0.049
1973	-0.243	-0.193	-0.049
1974	-0.248	-0.207	-0.041
1975	-0.230	-0.186	-0.044
1976	-0.222	-0.186	-0.036
1977	-0.230	-0.189	-0.041
1978	-0.216	-0.189	-0.028
1979	-0.221	-0.170	-0.051
1980	-0.218	-0.175	-0.043
1981	-0.212	-0.173	-0.039
1982	-0.205	-0.183	-0.023
1983	-0.223	-0.182	-0.041
1984	-0.249	-0.201	-0.048
1985	-0.261	-0.195	-0.065
1986	-0.301	-0.185	-0.116
1987	-0.301	-0.182	-0.119
1988	-0.324	-0.193	-0.132
1989	-0.303	-0.197	-0.106
1990	-0.282	-0.201	-0.081
1991	-0.283	-0.194	-0.089
1992	-0.278	-0.198	-0.080

Note: ε_{CR} are computed from equation (4.24): It reflects the percent change in total cost associated with a one percent increase in R&D expenditures, holding capital stock fixed. The inter-country difference in the dual rate of technological change is computed following (4.30b)

Figure 5.4: Difference in the Dual Rate of Technological Change Between the U.S. and Canadian Food Sectors



5.8 Capacity Utilization

Capacity utilization measures (CU) in the U.S. and Canada were computed according to equation (4.33). The results are reported in table 5.8. Recall that if CU is greater than one, capital valuation at the margin exceeds market value. As a consequence, capital is overutilized and a capacity shortage prevails. Conversely, if CU is below one, underutilization of capital prevails. Finally, if CU equals one, the sector is in long-run equilibrium and operates at the minimum point on its SRAC curve (and its LRAC under CRTS).

The relative constancy of our capacity utilization estimates in table 5.8 was surprising and should be interpreted with some caution. It may reflect the absence in our model of an adjustment cost term on other dynamic component, although multicollinearity problems prevented the inclusion of such terms. Overall, the present results suggest that the Canadian food sector operates in the neighborhood of the minimum of its short-run average total cost curve, implying that Canada has remained near its long-run equilibrium. After 1974, we note a slight downward trend in Canadian capacity utilization. In contrast, table 5.8 suggests the U.S. food sector operates at the right of the minimum point of the average cost curve, implying a capacity shortage over the entire sample period. As a consequence, failure to take account of capacity utilization would have resulted in overestimating the true R&D-related productivity growth in the U.S.

Capacity utilization in the U.S. and Canadian food sectors helps explain the inter-country performance differential in terms of output growth and cost reduction associated with R&D, discussed in the previous section. Using equations (3.25) and (3.7) the primal and dual measures of technological change are related to capacity utilization as follow (Morrison 1992):

$$- \varepsilon_{CR} = \varepsilon_{YR}\varepsilon_{CY}^{SR} = \varepsilon_{YR}CU \quad (5.2)$$

Equation (5.2) is possible because under long-run constant returns to scale, capacity utilization equals the short-run cost elasticity of output (see equation 3.25).[16] That is, under a short-run equilibrium framework and long-run constant returns to scale, ε_{CY}^{SR} (i.e. short-run cost elasticity with respect to output) can be interpreted as capacity utilization (Morrison, 1986). The primal technological effect of R&D (i.e. ε_{YR}) is thus given by the ratio of ε_{CR} (technology growth effect of R&D) to capacity utilization. In Canada, the shift of the production function (ε_{YR}) and cost function (ε_{CR}) associated with R&D expenditure approximately equal one another because CU is close to one, while in the U.S. the shift of the production function associated with R&D is less than the shift in the cost function. In other words, the inter-country difference in the primal technological effect of R&D takes into account the inter-country difference in capacity utilization. As a result, the Canadian food sector is at no disadvantage to the U.S. in terms of R&D-induced output growth even though it does have a disadvantage in terms of R&D-induced cost reductions over the entire sample period. Once again, given the constancy of the capacity utilization index in both the U.S. and Canada, we are hesitant to assert that the U.S. food sector overutilizes capital compared to Canada. However, our results do prove that capacity utilization affects inter-country differential in the primal rate of technological change.

[16] From Morrison (1992), $\varepsilon_{CY}^{SR} = \varepsilon_{CY}^{LR}(1-\varepsilon_{CK}) = \varepsilon_{CY}^{LR} * CU$

Table 5.8: Capacity Utilization in the U.S. and Canadian Food Sectors

YEAR	U.S.	CANADA
1963	1.213	0.927
1964	1.212	0.933
1965	1.210	0.950
1966	1.203	0.959
1967	1.209	0.970
1968	1.213	0.998
1969	1.214	0.994
1970	1.214	1.000
1971	1.212	1.002
1972	1.226	0.997
1973	1.245	0.991
1974	1.254	1.009
1975	1.208	0.995
1976	1.230	0.976
1977	1.240	0.974
1978	1.250	0.975
1979	1.259	0.967
1980	1.261	0.978
1981	1.252	0.977
1982	1.236	0.976
1983	1.235	0.968
1984	1.218	0.976
1985	1.213	0.962
1986	1.212	0.955
1987	1.201	0.945
1988	1.199	0.959
1989	1.196	0.966
1990	1.181	0.962
1991	1.189	0.944
1992	1.198	0.945

Note: Figures shown are CU = ε_{CR}^{SR}, computed following equation (4.33).

5.9 Long-Run Productivity Growth Effects of R&D

Technology-growth impacts of R&D presented in section 5.6 are short-run indicators of U.S. and Canadian food sector performance. The productivity-growth impact of R&D, in contrast, is a long-run equilibrium concept representing the downward shift of the long-run average cost curve. From equation (4.27), the dual of long-run productivity growth is defined as a weighted sum of the rate of change in unit variable cost due to R&D and the rate of change in the ratio of capital to output due to R&D. The decrease in average variable cost can, in turn, be decomposed into a technological change component and a capacity utilization component. The latter results from changes in capital stock as firms move toward their long-run equilibrium (equation 4.28).

Turning to the results, tables 5.9 and 5.10 reveal that long-run productivity growth in the U.S. and Canadian food sector has been caused mainly by decreases in average variable cost, while the effect of changes in unit capital cost have been minor. Decomposing the rate of change of unit variable cost into its sources reveals that, overall, technological change contributes directly to 95% of the long-run productivity growth in both the U.S. and Canada. It is interesting that, in the U.S, capacity utilization had the greatest impact on cost reduction in 1973, 1976-77 and 1979-80. Indeed, the effect of changing capital stock accounts for 81% of productivity growth in 1973, and for an average of 50% of productivity growth between 1976 and 1980.

Table 5.9a: Long-Run Dual Rate of Productivity Growth Associated with R&D, United States.

Year	Productivity Growth	Source of Productivity growth			
		AVC growth	Source of AVC growth		Capital Growth
			Technological change	CU effect	
1963	-0.160	-0.152	-0.179	-0.027	-0.008
1964	-0.148	-0.127	-0.198	-0.071	-0.020
1965	-0.185	-0.176	-0.208	-0.032	-0.009
1966	-0.221	-0.227	-0.207	0.020	0.006
1967	-0.191	-0.178	-0.222	-0.043	-0.012
1968	-0.243	-0.248	-0.229	0.018	0.005
1969	-0.254	-0.261	-0.236	0.024	0.007
1970	-0.247	-0.252	-0.235	0.017	0.005
1971	-0.278	-0.295	-0.237	0.058	0.017
1972	-0.260	-0.263	-0.250	0.013	0.003
1973	-1.108	-1.313	-0.243	1.070	0.204
1974	-0.217	-0.211	-0.248	-0.037	-0.006
1975	-0.154	-0.119	-0.230	-0.111	-0.035
1976	-0.355	-0.401	-0.222	0.179	0.046
1977	-0.482	-0.563	-0.230	0.333	0.082
1978	0.168	0.273	-0.216	-0.489	-0.105
1979	-0.378	-0.416	-0.221	0.195	0.038
1980	-0.429	-0.481	-0.218	0.263	0.052
1981	-0.242	-0.251	-0.212	0.039	0.009
1982	-0.204	-0.204	-0.205	-0.001	0.000
1983	-0.235	-0.240	-0.223	0.017	0.005
1984	-0.237	-0.232	-0.249	-0.018	-0.006
1985	-0.204	-0.176	-0.261	-0.085	-0.028
1986	-0.309	-0.312	-0.301	0.011	0.004
1987	-0.335	-0.354	-0.301	0.053	0.019
1988	-0.316	-0.311	-0.324	-0.013	-0.005
1989	-0.308	-0.310	-0.303	0.007	0.002
1990	-0.206	-0.151	-0.282	-0.131	-0.054
1991	-0.599	-0.811	-0.283	0.528	0.212
1992	-0.067	0.069	-0.278	-0.347	-0.135
1993	-0.386	-0.442	-0.283	0.159	0.057

Note: Computed following equation (4.29).

Table 5.9b Contributions to Productivity Growth (%) in the U.S. Food Sector

Year	Productivity Growth	% Source of Productivity Growth		Rate of AVC Growth	% Source of AVC Growth	
		AVC Growth	Capital Growth		Technological Change	CU Effect
1963	-0.160	95.1	4.9	-0.152	117.9	-17.9
1964	-0.148	86.3	13.7	-0.127	155.8	-55.8
1965	-0.185	95.1	4.9	-0.176	118.4	-18.4
1966	-0.221	102.7	-2.7	-0.227	91.3	8.7
1967	-0.191	93.6	6.4	-0.178	124.4	-24.4
1968	-0.243	102.1	-2.1	-0.248	92.6	7.4
1969	-0.254	102.6	-2.6	-0.261	90.8	9.2
1970	-0.247	101.9	-1.9	-0.252	93.1	6.9
1971	-0.278	106.0	-6.0	-0.295	80.2	19.8
1972	-0.260	101.2	-1.2	-0.263	95.1	4.9
1973	-1.108	118.4	-18.4	-1.313	18.5	81.5
1974	-0.217	97.1	2.9	-0.211	117.7	-17.7
1975	-0.154	77.5	22.5	-0.119	192.5	-92.5
1976	-0.355	112.9	-12.9	-0.401	55.4	44.6
1977	-0.482	117.0	-17.0	-0.563	40.9	59.1
1978	0.168	162.5	-62.5	0.273	-79.3	179.3
1979	-0.378	110.2	-10.2	-0.416	53.1	46.9
1980	-0.429	112.2	-12.2	-0.481	45.3	54.7
1981	-0.242	103.7	-3.7	-0.251	84.5	15.5
1982	-0.204	99.8	0.2	-0.204	100.7	-0.7
1983	-0.235	102.0	-2.0	-0.240	92.9	7.1
1984	-0.237	97.7	2.3	-0.232	107.6	-7.6
1985	-0.204	86.4	13.6	-0.176	148.1	-48.1
1986	-0.309	101.2	-1.2	-0.312	96.5	3.5
1987	-0.335	105.6	-5.6	-0.354	85.1	14.9
1988	-0.316	98.5	1.5	-0.311	104.3	-4.3
1989	-0.308	100.8	-0.8	-0.310	97.9	2.1
1990	-0.206	73.5	26.5	-0.151	186.9	-86.9
1991	-0.599	135.5	-35.5	-0.811	34.9	65.1
1992	-0.067	-103.5	203.5	0.069	-403.4	503.4
1993	-0.386	114.8	-14.8	-0.442	64.0	36.0

Note: Col(3) and col(4) of this table equal col(3)/col(2) and col(6)/col(2), respectively, of table 5.9a. Col(6) and col(7) of this table equal col(4)/col(2) and col(5)/col(2), respectively, of table 5.9a.

Table 5.10a: Long-Run Dual Rate of Productivity Growth Associated with R&D, Canada

Year	Productivity Growth	Source of Productivity growth			
		AVC growth	Source of AVC growth		K effect
			Technological change	CU effect	
1964	-0.110	-0.095	-0.098	-0.003	-0.015
1965	-0.130	-0.123	-0.125	-0.002	-0.008
1966	-0.142	-0.138	-0.139	-0.002	-0.004
1967	-0.164	-0.165	-0.164	0.001	0.001
1968	-0.207	-0.180	-0.199	-0.019	-0.026
1969	-0.174	-0.204	-0.185	0.020	0.030
1970	-0.180	-0.233	-0.194	0.040	0.053
1971	-0.191	-0.207	-0.196	0.011	0.015
1972	-0.217	-0.154	-0.201	-0.047	-0.062
1973	-0.199	-0.179	-0.193	-0.014	-0.020
1974	-0.206	-0.213	-0.207	0.006	0.007
1975	-0.172	-0.223	-0.186	0.037	0.050
1976	-0.288	-0.046	-0.186	-0.140	-0.243
1977	-0.228	-0.142	-0.189	-0.047	-0.086
1978	-0.187	-0.190	-0.189	0.002	0.003
1979	-0.197	-0.147	-0.170	-0.024	-0.050
1980	-0.192	-0.153	-0.174	-0.021	-0.039
1981	-0.152	-0.199	-0.173	0.026	0.047
1982	-0.098	-0.294	-0.183	0.111	0.196
1983	-0.178	-0.186	-0.182	0.004	0.008
1984	-0.183	-0.229	-0.201	0.028	0.047
1985	-0.180	-0.211	-0.195	0.016	0.031
1986	-0.159	-0.207	-0.185	0.022	0.048
1987	-0.207	-0.165	-0.182	-0.017	-0.041
1988	-0.121	-0.263	-0.193	0.070	0.142
1989	-0.120	-0.290	-0.197	0.093	0.169
1990	-0.252	-0.140	-0.201	-0.061	-0.112
1991	-0.071	-0.307	-0.194	0.113	0.236
1992	-0.191	-0.204	-0.198	0.006	0.013

Note: Computed following equation (4.29).

Table 5.10b: Contributions to Productivity Growth (%) in the Canadian Food Sector

Year	Productivity Growth	Source of Productivity Growth		Rate of AVC Growth	Source of AVC Growth	
		AVC Growth	Capital Growth		Technological Change	CU Effect
1963	-0.110	86.0	14.0	-0.095	103.3	-3.3
1964	-0.130	94.2	5.8	-0.123	101.9	-1.9
1965	-0.142	96.9	3.1	-0.138	101.2	-1.2
1966	-0.164	100.7	-0.7	-0.165	99.7	0.3
1967	-0.207	87.3	12.7	-0.180	110.3	-10.3
1968	-0.174	117.3	-17.3	-0.204	90.4	9.6
1969	-0.180	129.7	-29.7	-0.233	83.1	16.9
1970	-0.191	108.0	-8.0	-0.207	94.8	5.2
1971	-0.217	71.3	28.7	-0.154	130.3	-30.3
1972	-0.199	89.8	10.2	-0.179	108.0	-8.0
1973	-0.206	103.2	-3.2	-0.213	97.3	2.7
1974	-0.172	129.3	-29.3	-0.223	83.3	16.7
1975	-0.288	15.8	84.2	-0.046	406.1	-306.1
1976	-0.228	62.2	37.8	-0.142	133.2	-33.2
1977	-0.187	101.7	-1.7	-0.190	99.1	0.9
1978	-0.197	74.5	25.5	-0.147	116.0	-16.0
1979	-0.192	79.6	20.4	-0.153	114.0	-14.0
1980	-0.152	130.6	-30.6	-0.199	86.9	13.1
1981	-0.098	299.5	-199.5	-0.294	62.1	37.9
1982	-0.178	104.4	-4.4	-0.186	97.8	2.2
1983	-0.183	125.6	-25.6	-0.229	87.9	12.1
1984	-0.180	117.3	-17.3	-0.211	92.5	7.5
1985	-0.159	130.3	-30.3	-0.207	89.3	10.7
1986	-0.207	80.0	20.0	-0.165	110.2	-10.2
1987	-0.121	217.5	-117.5	-0.263	73.3	26.7
1988	-0.120	241.0	-141.0	-0.290	68.1	31.9
1989	-0.252	55.5	44.5	-0.140	143.7	-43.7
1990	-0.071	435.0	-335.0	-0.307	63.1	36.9
1991	-0.191	106.9	-6.9	-0.204	96.9	3.1
1992	-0.067	-103.5	203.5	0.069	-403.4	503.4
1993	-0.386	114.8	-14.8	-0.442	64.0	36.0

Note: Col(3) and col(4) of this table equal col(3)/col(2) and col(6)/col(2), respectively, of table 5.10a. Col(6) and col(7) of this table equal col(4)/col(2) and col(5)/col(2), respectively, of table 5.10a.

5.10 Rates of Return to R&D

The rates of return to R&D expenditures presented in table 5.11 give the gain in dollar terms of investing one more dollar in the food manufacturing sector. The estimates reveal that one more dollar invested in R&D in Canada brings a higher return than it does in the U.S. At sample mean, the net gain is 130 dollars in Canada for each dollar invested in R&D, compared to 90 dollars in the U.S. Table 5.11 also reveals that the rate of return to R&D has generally decreased over time both in Canada and in the U.S. However, when rate of return is plotted against time, more variations are seen from year to year in Canada than in the U.S. It would appear that the rather smooth pattern observed in R&D returns in the U.S. arises from the comparative stability of R&D expenditures in the U.S. from one year to the next.

The rates of return to R&D reported here are considerably higher than those reported in most of the literature, which appear to average 30 cents for each dollar invested. However, such comparisons should be made with care because:

- We were not able to disentangle the R&D expenditures devoted to product innovation from those devoted to process innovation.
- Use of highly aggregate data does not permit one to reflect much of the risk of R&D expenditure. The average rate of return should be high enough to pay for the cost of risk, and this tends to justify the high average rates of return estimated in this study.
- Spillovers between countries are not taken into account.
- Research expenditures used here are current expenditures only rather than representative of the stock of R&D capital.

It is interesting to note that the rate of return to R&D in Canada is higher than in the U.S. even though the elasticity of cost with respect to R&D expenditure is lower in Canada (see table 5.7) than in the U.S. The difference between R&D's elasticity and dollar rate of return can be explained by the law of diminishing returns: as investment in R&D increases, the incremental return to it should decrease. Expressing the intensity of

R&D investment in terms of the ratio of R&D to shipment value reveals that Canada invests less in R&D than does the U.S. Indeed, the ratio of R&D expenditure to shipment value between 1962 and 1992 averaged 0.15% in Canada and 0.23% in the U.S. A further reason for the higher rate of return to R&D in Canada is the inter-country technology spillover from U.S. to Canada, which is not taken into account in our model. (Industry Canada, working paper no.3).

Table 5.11: Rate of Return to One Dollar of R&D Expenditure in the U.S. and Canadian Food Sectors (U.S.$)

YEAR	U.S.	CANADA
1963	91	142
1964	96	155
1965	95	159
1966	93	150
1967	97	140
1968	97	129
1969	93	145
1970	95	144
1971	95	157
1972	94	138
1973	93	137
1974	91	130
1975	91	138
1976	97	139
1977	97	131
1978	94	121
1979	89	124
1980	83	119
1981	83	121
1982	83	114
1983	81	116
1984	78	106
1985	80	106
1986	76	114
1987	73	119
1988	70	126
1989	73	126
1990	73	123
1991	73	129
1992	75	124

Note: Computed following equation (4.31).

5.11 Primal and Dual Rates of Technological Change in the Time Domain

The indicators of productivity and technological change discussed above have been attributed to R&D expenditure only. In this sense, they are slightly different from those usually derived in literature, where time rather that R&D expenditure typically is used to represent the exogenous variable. The idea behind using a time trend is to capture the impacts on cost or output not accounted for by the independent variables. Derivatives $\partial \ln Y/\partial t$ and $\partial \ln C/\partial t$ thus represent the proportional shift of the production and cost function, respectively, through time and are defined as technological change (Antle and Capalbo, 1988).

In the present study, I was unsuccessful in using time as a proxy for technology change because time and many of the explanatory variables were multicollinear with one another. R&D expenditure was used instead, as it is one of the main factors driving the level of technology in a country or sector. As a consequence, the effect of the non-R&D factors such as learning, which might also have decreased cost or increased output, are not captured by ε_{YR} or ε_{CR}. An alternative specification, which included a time trend slope parameter in the translog variable cost equation along with R&D expenditure, was attempted to try to capture these non-R&D effects. However, the point estimate of the time trend parameter was insignificant, again presumably due to multicollinearity.

Nevertheless, assuming that R&D expenditure is highly correlated with the non-R&D factors inducing productivity growth, the percentage change of cost and output with respect to time can be approximated from what we *have* estimated as follows:

$$\varepsilon_{Ct} = \varepsilon_{CR}\,\varepsilon_{Rt}$$

$$\varepsilon_{Yt} = \varepsilon_{YR}\,\varepsilon_{Rt} \qquad (5.3)$$

where ε_{Rt} is the proportionate rate of change in R&D expenditure over time, ε_{Ct} is the proportionate reduction in cost over time, and ε_{Yt} is the proportionate increase in output over time. The results are reported in table 5.12. The bottom of the table provides the averages of the rates in selected time periods.

The results exhibit trends similar to the R&D primal and dual technological change effects discussed earlier. On the cost side, technological change occurred at an average annual rate of 1.53% in the U.S. between 1963 and 1972. A significant decline in this rate appeared during the 1973-82 period, when it averaged a negative 0.11%. From 1982 to 1988, however, the proportionate reduction in cost over time occurred at an average rate of 4%, followed by a decline between 1988 and 1993. On the output side, a similar pattern is observed.

In Canada, the 1963-72 period was, as expected, a period of fast growth, with an average annual rate of cost reduction of 2.64% and an average output growth rate of 2.79%. From 1973 to 1982, the average growth rates dropped to 0.31% on both the cost and output side, increasing again between 1983 and 1988. After 1988, Canada appears to have moved into a negative growth mode. This negative growth is surprising. A closer look at the data reveals that it is a result of two shocks: (i) in 1990, technological change grew at a negative rate of 1.45% (in the primal) and 1.32% (in the dual); (ii) in 1992, technological change grew at a negative rate of 1.16% and 1.39% in the primal and dual respectively.

Comparing the U.S. to Canada, my findings are as before: the Canadian food processing sector had higher growth than the U.S. did before 1982, but lower growth thereafter.

Table 5.12: Primal and Dual Rates Technological Change with Respect to Time

YEAR	US		CANADA	
	ε_{Ct}	ε_{Yt}	ε_{Ct}	ε_{Yt}
1963	-1.548	1.276	-4.018	4.416
1964	-2.047	1.689	-4.000	4.314
1965	-1.994	1.648	-3.000	3.202
1966	-1.239	1.031	-4.930	5.214
1967	-1.589	1.314	-7.486	7.686
1968	-1.214	1.001	1.989	-2.047
1969	-2.379	1.960	-1.580	1.616
1970	-0.188	0.155	-0.532	0.544
1971	-0.436	0.360	-2.359	2.428
1972	-2.646	2.159	-0.533	0.551
1973	-0.369	0.296	-3.362	3.407
1974	-0.947	0.755	3.261	-3.354
1975	1.885	-1.561	-0.748	0.786
1976	1.488	-1.210	-0.683	0.718
1977	-0.753	0.607	-1.250	1.313
1978	-0.273	0.218	1.904	-2.013
1979	-1.072	0.851	-0.548	0.571
1980	-0.161	0.128	0.440	-0.460
1981	1.047	-0.836	-2.013	2.113
1982	0.260	-0.210	-0.162	0.172
1983	-2.831	2.291	-4.114	4.331
1984	-4.925	4.044	0.686	-0.735
1985	-1.240	1.022	1.379	-1.488
1986	-8.476	6.995	-0.379	0.414
1987	-1.692	1.409	-1.503	1.616
1988	-5.201	4.338	-0.599	0.640
1989	2.534	-2.120	-0.825	0.888
1990	1.791	-1.516	1.324	-1.458
1991	-0.296	0.249	-0.536	0.590
1992	0.882	-0.736	1.399	-1.168
PERIOD	AVERAGE RATES			
1963-72	-1.528	1.259	-2.645	2.792
1973-82	0.111	-0.096	-0.316	0.325
1983-88	-4.061	3.350	-0.755	0.796
1988-83	0.863	-0.726	0.341	-0.287
1963-93	-1.154	0.947	-0.844	0.907

Note: ε_{Ct} and ε_{Yt} are computed following equations (5.3).

Chapter 6: Conclusions and Implications

An industrial sector's international competitiveness rests partly on technological improvements resulting from investments in R&D. Technological change, in turn, induces productivity growth. Technological change and productivity growth serve to decrease cost or increase output. In the present study, I assessed the relative competitiveness of the U.S. and Canadian food processing sector in a short-run equilibrium framework. First, the performance of each country's food processing sector was compared in terms of cost reduction and output increases associated with R&D expenditure, holding capital fixed. Next, the long-run dual rate of productivity growth was computed and decomposed into their sources. Finally, the rate of return to R&D was estimated.

Expressed in terms of the cost reduction or output increase resulting from a proportionate increase in R&D expenditures, the U.S. and Canadian food sectors exhibit similar performance trends over the 1963-1993 period. Only some of the details of timing and magnitude differ. Indeed, the technological change and primal productivity growth effects of R&D expenditure:

- grew quickly in the U.S. from 1962 to 1972 and in Canada from 1963 to 1974.
- declined in the U.S. between 1973 and 1982 and in Canada from 1975 to 1981.
- increased again in the U.S. between 1983 and 1988 in the U.S. and in Canada from 1982 to 1984.

After 1988, however, the primal and dual technological growth associated with R&D expenditures declined in the U.S. while they increased in Canada. The sharpest increase in the primal and dual rates of technological change occurred in the U.S. between 1982 and 1988, which coincided with a period of intensive structural change. The effect of the 1973 recession was more severe in the U.S. than in the Canadian food sector, while the early 1980's recession hit the Canadian food sector more severely than it did the U.S. sector.

Our results suggest the U.S. has, in dual terms, a net technological advantage over Canada in the sense of enjoying a higher cost reduction from R&D expenditure. After adjusting for capacity utilization to obtain output growth associated with R&D expenditure, i.e. the primal measure of technological change, this net cost advantage is lost. Indeed, our estimates of capacity utilization suggest that the Canadian food sector operates at close to full capacity, while the U.S. food sector overuse its fixed capital. The comparative constancy of our capacity utilization index over the sample period cast some doubt on the reliability of this index and precludes us from deriving further policy implications from it. Nonetheless, the results do show that deviation from full capacity has an impact on the rate of productivity growth, both in the short run and in the long run.

Decomposing the long-run productivity growth rate into its components reveals that, in both the U.S. and Canada, technological change is the main factor inducing productivity growth. Variations in capital stock resulting from R&D expenditures had only a minor effect.

Despite a lower percentage rate of cost reduction in Canada from R&D expenditure, the dollar return to R&D is higher in Canada than in the U.S. This finding can be explained through the law of diminishing return since Canadian expenditures on R&D per unit of shipment value are, on average, 8% less than in the United States.

Implications

Following trade liberalization and the ratification of North American Free Trade Agreement (NAFTA), the ability to produce at lower cost (i.e. cost efficiency) has become a key element in the competition among food manufacturers. The present study has shown that productivity growth in food processing has been accounted for primarily by technological change, which in turn is largely possible by R&D expenditures. Therefore, R&D investment is a strategic element in ensuring a better long-run competitive position, that is in maintaining market share and in taking advantage of new opportunities.

It is desirable for food processors to have flexibility in adapting to exogenous changes in either the short run or long run. Flexibility translates into the degree of substitutability between factors of production, which permits a firm to respond quickly to changes in input prices. The United States' superior technological growth rate has come at the cost of higher capital intensivity in terms of the ratio of capital to labor, which in turn is responsible for the lower substitutability in the U.S. between labor and materials. This lower substitutability renders the U.S. food industry more vulnerable to price shocks and thus may place its competitive advantage in periodic jeopardy.

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APPENDICES

APPENDIX A: ALGEBRAIC PROOFS

A-1 Proof of Equation (4.25): $\varepsilon_{CY}^{SR} = \varepsilon_{VCY}(VC/C)$

Short run total cost, that is total cost when the assumption that capital is fixed, is

$$C = VC(Y, K, R) + p_k K \tag{A1}$$

Differentiating (A1) with respect to Y gives

$$\frac{\partial C}{\partial Y} = \frac{\partial VC}{\partial Y} = \text{marginal cost} \tag{A2}$$

We know that

$$\frac{\partial \ln C}{\partial \ln Y} = \frac{\partial C}{\partial Y}\frac{Y}{C}$$

and

$$\frac{\partial \ln VC}{\partial \ln Y} = \frac{\partial VC}{\partial Y}\frac{Y}{VC}.$$

Since Y/C ≠ Y/VC, it follows that $\frac{\partial \ln C}{\partial \ln Y} \neq \frac{\partial \ln VC}{\partial \ln Y}$. However, using (A2), $\frac{\partial \ln C}{\partial \ln Y}$ can be rewritten as

$$\frac{\partial \ln C}{\partial \ln Y} = \frac{\partial C}{\partial Y}\frac{Y}{C} = \frac{\partial VC}{\partial Y}\frac{Y}{C} = \frac{\partial VC}{\partial Y}\frac{Y}{VC}\frac{VC}{C} = \frac{\partial \ln VC}{\partial \ln Y}\frac{VC}{C} \tag{A3}$$

Thus,

$$\varepsilon_{CY} = \varepsilon_{VCY}\,(VC/C). \tag{A4}$$

A-2 Proof of Equation (4.24): $\varepsilon_{CR} = \varepsilon_{VCR}\,(VC/C)$

If capital quantity K is assumed fixed with respect to R&D expenditure R, the partial derivative of equation (A1) with respect to R is:

$$\frac{\partial C}{\partial R} = \frac{\partial VC}{\partial R} = \text{negative of rate of return to R\&D.} \tag{A5}$$

The logarithmic forms of (A5) are

$$\frac{\partial \ln C}{\partial \ln R} = \frac{\partial C}{\partial R}\frac{R}{C}$$

and

$$\frac{\partial \ln VC}{\partial \ln R} = \frac{\partial VC}{\partial R}\frac{R}{VC}.$$

Substituting (A5) into $\frac{\partial \ln C}{\partial \ln R} = \frac{\partial C}{\partial R}\frac{R}{C}$ gives

$$\frac{\partial \ln C}{\partial \ln R} = \frac{\partial C}{\partial R}\frac{R}{C} = \frac{\partial VC}{\partial R}\frac{R}{C} = \frac{\partial VC}{\partial R}\frac{R}{VC}\frac{VC}{C} = \frac{\partial \ln VC}{\partial \ln R}\frac{VC}{C} \tag{A6}$$

Thus, $\varepsilon_{CR} = \varepsilon_{VCR}\,(VC/C)$. (A4)

A-3 Derivation of the Dual Productivity Growth Rate (equation 4.29)

The logarithmic form of (A1) is

$$\ln C = \ln (VC + p_k K) \tag{A5}$$

The total derivative of (A5) with respect to the log of R is:

$$\left.\frac{d\ln C}{d\ln R}\right|_W = \frac{d\ln(VC + p_k K)}{d\ln R} = \frac{R}{C}\left(\frac{dVC}{dR} + \frac{d(p_k K)}{dR}\right) \tag{A6}$$

Using C = AC•Y, (A6) can be rewritten as

$$\left.\frac{d\ln(AC \bullet Y)}{d\ln R}\right|_W = \frac{d\ln AC}{d\ln R} + \frac{d\ln Y}{d\ln R} = \frac{d\ln(VC + p_k K)}{d\ln R} = \frac{R}{C}\left(\frac{dVC}{dR} + \frac{d(p_k K)}{dR}\right).$$

Thus, holding input prices fixed, the dual rate of productivity growth, dlnAC/dlnR, is given by

$$\left.\frac{d\ln AC}{d\ln R}\right|_W = \frac{R}{C}\left(\frac{dVC}{dR} + \frac{p_k dK}{dR}\right) - \frac{d\ln Y}{d\ln R} \tag{A7}$$

Substituting dVC/dR = (dlnVC/dlnR)(VC/R) and dK/dR = (dlnK/dlnR)(K/R) into (A7) and rearranging gives:

$$\left.\frac{d\ln AC}{d\ln R}\right|_W = \left(\frac{VC}{C}\frac{d\ln VC}{d\ln R}\right) + \left(\frac{p_k K}{C}\frac{d\ln K}{d\ln R}\right) - \frac{d\ln Y}{d\ln R} \tag{A8}$$

Substituting VC = AVC•Y into (A8) where AVC is average variable cost, and rearranging gives

$$\left.\frac{d\ln AC}{d\ln R}\right|_W = \left(\frac{VC}{C}\frac{d\ln AVC}{d\ln R}\right) + \left(\frac{VC}{C}\frac{d\ln Y}{d\ln R}\right) + \left(\frac{p_kK}{C}\frac{d\ln K}{d\ln R}\right) - \frac{d\ln Y}{d\ln R} \qquad \text{(A9)}$$

Since (VC/C) - 1 = $-p_kK/C$, we have

$$\left.\frac{d\ln AC}{d\ln R}\right|_W = \frac{VC}{C}\left(\frac{d\ln AVC}{d\ln R}\right) + \frac{p_kK}{C}\left(\frac{d\ln K}{d\ln R} - \frac{d\ln Y}{d\ln R}\right) \qquad \text{(A10)}$$

A-4 Decomposing the Reduction in Unit Variable Cost, dlnAVC/dlnR, into its Components

From equation (5.10), the general form of the translog variable cost equation is:

$$\ln VC = G(\ln \mathbf{W},\ \ln Y, \ln K, \ln R) \qquad \text{(A11)}$$

The growth in variable cost owing to R&D expenditure, holding input prices fixed, is:

$$\left.\frac{d\ln VC}{d\ln R}\right|_W = \left(\frac{\partial \ln VC}{\partial \ln Y}\frac{d\ln Y}{d\ln R}\right) + \left(\frac{\partial \ln VC}{\partial \ln K}\frac{d\ln K}{d\ln R}\right) + \frac{\partial \ln VC}{\partial \ln R} \qquad \text{(A12)}$$

Substracting both sides of (A12) by dlnY/dlnR gives the reduction in average variable cost induced by R&D expenditures:

$$\left.\frac{d\ln AVC}{d\ln R}\right|_W = \left(\frac{\partial \ln VC}{\partial \ln Y} - 1\right)\frac{d\ln Y}{d\ln R} + \left(\frac{\partial \ln VC}{\partial \ln K}\frac{d\ln K}{d\ln R}\right) + \frac{\partial \ln VC}{\partial \ln R} \qquad \text{(A13)}$$

Using $\frac{\partial nVC}{\partial nY} = \varepsilon_{VCY}$, $\frac{\partial nVC}{\partial nK} = \varepsilon_{VCK}$ and $\frac{\partial nVC}{\partial nR} = \varepsilon_{VCR}$ (from equations (4.10), (4.34), and (4.22), respectively) and assuming that $\varepsilon_{VCY} + \varepsilon_{VCK} = 1$ (by LRCRTS), equation (A13) can be rewritten as

$$\left.\frac{d\ln AVC}{d\ln R}\right|_{W} = \left[\varepsilon_{VCR} + \varepsilon_{VCK}\left(\frac{d\ln K}{d\ln R} - \frac{d\ln Y}{d\ln R}\right)\right] \quad \text{(A14)}$$

Substituting (A14) in (A10) gives the dual rate of productivity growth in equation (4.29):

$$-\left.\frac{d\ln AC}{d\ln R}\right|_{W} = \frac{VC}{C}\left[\varepsilon_{VCR} + \varepsilon_{VCK}\left(\frac{d\ln K}{d\ln R} - \frac{d\ln Y}{d\ln R}\right)\right] + \frac{p_k K}{C}\left[\frac{d\ln K}{d\ln R} - \frac{d\ln Y}{d\ln R}\right] \quad \text{(A15)}$$

APPENDIX B: Results of AR1 Model

Table B1: Translog Variable Cost Function Corrected for AR1, United States

Parameter	Variable	Estimate	T-Statistic
α_0	Constant	5.52	144.19
β_L	$(\ln W_l - \ln W_m)$	0.22	5.62
γ_{LL}	$0.5\,(\ln W_l - \ln W_m)^2$	0.13	4.64
λ_R	$(\ln R_{t-s} - \ln Y_{t-s})$	0.03	0.21
β_{LR}	$(\ln W_l - \ln W_m)(\ln R_{t-s} - \ln Y_{t-s})$	0.01	0.38
λ_{RR}	$0.5\,(\ln R_{t-s} - \ln Y_{t-s})^2$	-0.42	-0.86
τ_K	$(\ln K - \ln Y_t)$	-0.34	-13.19
β_{LK}	$(\ln W_k - \ln W_m)(\ln K - \ln Y_t)$	0.05	0.84
τ_{KK}	$0.5\tau_{KK}\,(\ln K - \ln Y_t)^2$	-0.28	-1.50
τ_{KR}	$(\ln K - \ln Y)(\ln R_{t-s} - \ln Y_{t-s})$	-0.03	-0.33
Equation			R^2
Variable cost			0.82
Share of labor			0.70
Output price			0.09
Log of likelihood function			291.83

Table B2: Translog Variable Cost Function Corrected for AR1, Canada

Parameter	Variable	Estimates	T-Statistic
α_0	Constant	3.37	32.21
β_L	$(\ln W_l - \ln W_m)$	0.29	16.85
γ_{LL}	$0.5\,(\ln W_l - \ln W_m)^2$	0.18	11.58
λ_R	$(\ln R_{t-s} - \ln Y_{t-s})$	-0.04	-0.27
β_{LR}	$(\ln W_l - \ln W_m)(\ln R_{t-s} - \ln Y_{t-s})$	-0.24E-02	-0.26
λ_{RR}	$0.5\,(\ln R_{t-s} - \ln Y_{t-s})^2$	-0.11	-0.29
τ_K	$(\ln K - \ln Y_t)$	-1.46	-11.16
β_{LK}	$(\ln W_k - \ln W_m)(\ln K - \ln Y_t)$	-0.08	-1.51
τ_{KK}	$0.5\tau_{KK}\,(\ln K - \ln Y_t)^2$	-0.99	-2.79
τ_{KR}	$(\ln K - \ln Y)(\ln R_{t-s} - \ln Y_{t-s})$	-0.01	-0.08
Equation			R^2
Variable cost			0.20
Share of labor			0.85
Output price			0.63E-03
Log of likelihood function			266.814

APPENDIX C: Environmental Regulations and Pollution Abatement Data Set

An econometric specification which included pollution abatement expenditures was attempted in order to estimate the effect of environmental regulations on productivity growth and technological change. I was unsuccessful in pursuing this specification due to multicollinearity. However, interested readers can find below the information on U.S. and Canadian environmental regulations, the pollution abatement data set, and the theoretical framework used in an attempt to incorporate pollution abatement expenditures into the model.

C-1 U.S. and Canadian Environmental Regulations

Since the 1970s, the growing concern about environmental damage has contributed to the growth of environmental regulations in the U.S. and Canada. A number of international agreements have been concluded in order to reduce the emission of some pollutants, among other objectives. A country's commitment to an international agreement will influence its environmental regulations. In this chapter, the firm-level economic implications of environmental regulation will first be discussed. Then, U.S. and Canadian pollution control expenditures will be compared. Finally, an overview of U.S. and Canadian environmental regulations will be presented, including a brief discussion of the industries affected by these laws in the food processing sector.

C-1.1 Firm-Level Implications of Environmental Regulations

Environmental regulations affect a firm mainly because they require it to comply with environmental standards. Two types of standards are used to achieve environmental quality objectives (Congressional Budget Office, 1985):

- Technology-based discharge standards specify the amount of pollutant a plant can emit at its source, and are established on the basis of the discharge that would occur if state-of-art control methods were used. This standard is usually expressed as a performance expectation, which specifies the discharge limitation regardless of method used. In some cases, discharge limits are not practical (for example in specifying hazardous waste disposal techniques) and the use of a particular abatement technology is then required. The latter is called an engineering standard.
- Ambient quality standards specify the maximum amount of pollutants allowed in a particular environmental medium. Examples are national ambient standards for air and water quality. Ambient quality standards can be considered as goals for environmental quality, guiding regulators in establishing discharge limits. Relatively tough discharge standards can be imposed in highly polluted areas.

In order to meet the required environmental standards, firms will either invest in new technology or improve their production process. End-of-pipe pollution controls are instituted with the sole objective of removing, abating, or controlling pollution without affecting the firm's production process. Therefore, End-of-pipe expenditures can easily be distinguished from other costs. In contrast to End-of-pipe investments, the integrated process or production process enhancement approach reduces pollution by changing the firm's production process. Changes in integrated processes to abate pollution are difficult to identify because: (i) firms may change their production process for purposes other than abating pollution (Craig and Lacroix, 1996); (ii) integrated processes can reduce emissions as well as improve the final product or enhance its productive efficiency (Jaffe et al, 1995).

Two lines of thought can be drawn regarding the economic effect on firms of environmental regulations. On the positive side, some economists argue that environmental regulations will increase productivity, as compliance with environmental standards induces the adoption of new technology, enhancing process efficiency. In addition, environmental regulations can decrease a firm's costs. For instance, as food manufacturing is a water-user-intensive industry, lower water effluents may decrease the cost processors pay for this factor of production (Jaffe et al, 1995).

On the negative side, environmental regulations impose additional costs on firms through the required investment in pollution abatement equipment. According to Haveman and Christainsen (1981), environmental standards tend to be engineering standards rather than performance standards. The latter does not require the use of a particular abatement technology. When the technique used for abating pollution is specified, more investment in pollution abatement capital might be required to meet an environmental standard than if the standard itself were the only regulation. Therefore, firm productivity may decrease as firms divert resources to the production of an additional output, in other words, to environmental quality (Jaffe et al, 1995).

C-1.2 U.S. and Canadian Investment in Pollution Abatement Capital

To provide a comparison of each country's spending on pollution control in the food sector, investment in pollution abatement capital as a percentage to total capital is presented in table C1.

Table C1 shows that the U.S. has devoted a higher proportion of its new capital expenditure on pollution than has Canada. However, these figures have to be interpreted with care as the data might not be fully comparable. Up to 1993, no survey had been conducted on pollution abatement capital expenditures (PACE) in Canada and the data that are available are approximate, as they were derived from a broader survey. In contrast, since 1973 the U.S. Bureau of Census has conducted an annual survey of firms' expenditures on pollution abatement capital. In 1994, Canada initiated a PACE survey comparable to the one conducted by the U.S. Bureau of Census. As in previous years, the 1994 share of pollution abatement capital to total capital expenditures was lower in Canada than in the U.S. Finally, a cross-country comparison by the CBO (1985) of pollution control expenditures as a percentage of the total GDP indicates that Canada spent less of its GDP on pollution abatement than did the United States.

Compared to other manufacturing sectors, food processing is a moderate polluter. The chemical and metallurgic industries, for example, invest a higher percentage of total capital in pollution abatement capital than does the food manufacturing sector. An investigation of food industry PACE by environmental medium reveals that water pollution abatement occupies the greatest share of total abatement expenditures, followed by air pollution and solid waste. In 1992 for example, water-borne pollutants accounted for 64% of total pollution control expenditures in the U.S., while air-borne and solid pollutants accounted respectively for 27% and 9%.

Table C1: U.S. and Canadian Investment in Pollution Abatement Capital as a Percentage of Total Capital Investment, Food Processing Sector, 1988-1993.

	1988	1991	1992	1993	1994
Canada	0.4	0.7	2.1	1.1	0.8
U.S.	2.8	5.15	3.2	2.3	2.7

Computed from:

- Department of Commerce, Bureau of Census (various year), *Pollution Abatement Cost and Expenditures*, MA-200
- Gagnon, Pierre (1995) *Private Sector Investments in Pollution Abatement and Control* in Statistics Canada (1995) *Environmental Perspective 3, Studies and Statistics* Catalogue No.11-528-XPE, No3: pp.11-16

C-1.3 U.S. and Canadian Environmental Regulation

In the U.S. and Canada, national and sub-national governments as well as municipalities share the responsibilities of designing, implementing, and enforcing environmental regulations. However, a major difference pertains to the degree of involvement of the national and sub-national governments in implementing environmental regulations. In the U.S., the federal government, through the Environmental Protection Agency (EPA), is responsible for designing and implementing most of the environmental regulations. The federal government can also specify the methods firms are required to follow in order to meet the standards. In contrast, in Canada the federal government's involvement is reduced to providing guidelines, while enforcement and implementation of regulations are under the provinces' jurisdiction. As a great number of regulations and laws can be found at each government level, my discussion will be limited to the principal laws impacting the food processing sector. Regulations can be divided into those pertaining to air, water, and solid waste pollution control. The main environmental laws in each country are presented below.

C-1.3.1 Air Pollution

In the U.S., air pollution control is enforced mainly under the federal Clean Air Act passed in 1970 (amended in 1977 and 1990). Under this Act, the federal government, through the EPA, is required to establish binding National Ambient Air Quality Standards (NAAQS) for major pollutants, such as carbon monoxide and ozone (Hoberg, 1992). Under close federal supervision, states in turn are responsible for implementing regulations in order to achieve the air emission standards. A failure to meet the standards may bring fines or penalties. Finally, discharge standards for new and existing air pollutants are established by the EPA under the Clean Air Act.

The Clean Air Act in Canada, passed in 1971 and incorporated in 1988 into the Canadian Environmental Protection Act, requires the federal government to establish guidelines for both air quality standards and discharge standards, with one exception. Provinces are encouraged, but not required, to follow the guidelines. They have the authority to set and implement their own air and discharge standards. An exception is that the Clean Air Act allows the federal government to impose national emission standards for air pollutants that could endanger public health (Hoberg, 1992). As in the U.S., pollutant emission is prohibited unless a firm has a permit to discharge. Regulatory authority can be transferred to municipalities. The city of Montreal, for example, has full power over air quality and pollutant regulations.

An example of a regulation affecting the food industry is the control of ozone-depleting substances. Canada has committed itself to meet Montreal's protocol schedule to decrease the use of ozone-depleting substances such as chlorofluorocarbons (CFC) and hydrofluorocarbons (HFC). In the food processing sector, ozone-depleting substances are found mainly in refrigeration, air conditioning, and fumigation. Therefore, industries that require chilling in the processing or preservation stages are affected. These primarily include meat, fish, fruit and vegetable processors, and breweries.

C-1.3.2 Water Pollution

In the U.S., states are required under the federal Water Pollution Control Act of 1972 to establish water quality standards. States are also responsible for enforcement of the standards under EPA approbation. Discharge standards are established by the EPA to control the maximum effluent limit in new and old plants. Standards are implemented by issuing permits for each source of effluent emission. Finally, all municipalities are required under the Water Pollution Control Act to install secondary treatment of municipal wastes (CBO, 1985).

In Canada, no water quality standards exist. Guidelines for discharged effluents are issued by the federal government under the Fisheries Act as amended in 1971. These standards must be met if effluents are discharged into any "fishable" water body (CBO, 1985). As for air pollution control, enforcement is carried out by the provinces.

However, the federal government has the right to enforcement in case of inappropriate provincial action. A discharge permit is required for any facility discharging into a municipal sewer. In addition, firms are subject to a monitoring and control requirement. If the limits are exceeded, surcharges can be levied, implying a significant cost to the firm. Regulation of water discharged is a provincial matter, through either a water quality act or a general environmental protection law. Finally, municipalities have their own laws for discharging to sewers (Marbek Resource Consultants, 1995).

The food sector industries most affected by water pollution control regulation are primary food processors and intensive water users such as meat, poultry, fish, fruit and vegetable and processors, dairy, breweries, and other beverage manufacturers (Marbek Resource Consultants, 1995).

C-1.3.3 Solid and Hazardous Waste

In the U.S., solid and hazardous waste control comes under the Resource Conservation and Recovery Act of 1977. This Act establishes requirements for the transportation, storage, and disposal of hazardous waste. States in turn are required to develop solid waste programs (CBO, 1985). In addition, the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 gives the federal government the authority to intervene in case of hazardous emergency spills.
In Canada, no federal regulations of solid and hazardous waste exist. Provinces and municipalities are responsible for solid waste management. Packaging waste has been identified in Canada as the major form of solid waste. A National Waste Reduction Strategy has been adopted by provinces and municipalities in order to reduce total packaging waste by half before the year 2000. The approach used is voluntary and preventive rather than regulatory (Marbek Resource Consultants, 1995). This commitment affects all industries, as well as all types of materials and all levels of packaging.

C-2 Pollution Abatement Data Set

In order to estimate the effect of environmental regulations on productivity growth, a data series on pollution abatement expenditures (PACE) in the food processing industry is required. I define total expenditures on pollution abatement as

$$E = W_k^{pa} * K^{pa} + OC^{pa} \tag{C.1}$$

where W_k^{pa} is the service price of pollution abatement capital, K^{pa} is the quantity of pollution abatement capital, and OC^{pa} is pollution abatement operating cost. Operating costs consist of labor, energy, materials, and service expenditures. To my knowledge, a data series for E as defined above is not available in either country. The computation performed in order to construct an E series in each country is described below.

C-2.1 U.S. Total Expenditure on Pollution Abatement

The Bureau of Census (BOC) has published annual data on pollution abatement operating costs from 1973 to 1992. Stocks of capital (in 1987 constant dollars) devoted to pollution abatement in the food processing industry from 1961 to 1991 are available through the Bureau of Economic Analysis (BEA).[1] Therefore, the missing components to determine an E series are: (i) the stock of pollution abatement capital in 1992 and (ii) a series for service price W_K^{pa}. The stock of pollution abatement capital in 1992 was computed by adding new investment in 1992 (provided by the Bureau of Census) to the existing capital stock net of depreciation, following the Perpetual Inventory Method (PIM). The stock series was then converted to the 1992 base year using the BEA's air and water pollution abatement price index as a deflator.

[1] Unfortunately, solid waste PACE was not considered in the BEA estimation. However, the BEA annual survey on new PAC expenditure shows that in the food and kindred products industry, solid waste accounts for only a small portion of the new PAC expenditure. For instance in 1992, some $ 316.8

The service price of pollution abatement capital was computed using the dual of the PIM formula:

$$W_k^{pa} = (q^{pa}{}_{t-1})r_t + q_t\delta_t - (q_t - q_{t-1}) \tag{C.2}$$

where is q^{pa} is acquisition price of pollution abatement capital, r is the opportunity cost of capital, δ is rate of depreciation, and all terms on the right-hand-side refer to pollution abatement capital in the food processing industry. An index of acquisition prices of pollution abatement capital in the U.S. manufacturing sector, published by the BEA (1996), was employed as a proxy for q_t. The AAA corporate bond yield was used for r_t. Finally, δ_t was computed by dividing total depreciation value in constant dollars ($\delta_t K_t$) by net stock in constant dollars (K_t), as published by the BEA.

C-2.2 Canadian Total Expenditure on Pollution Abatement

In Canada, finding data on pollution abatement cost was problematic. The only historical information available are six years of data on abatement investments between 1985 to 1993. These data are only approximations, however, and are not pertinent to this study. In 1994, Statistics Canada initiated a national survey on new pollution abatement capital expenditures and operating costs that would be comparable to the U.S. data in terms of definition and methodological approach. No data have been assembled on the stock of pollution abatement capital. Consequently, I have computed a data series for capital service price, capital stock, and operating costs in Canada as follows.

First, note that our capital stock and capital service price series for total food manufacturing include pollution abatement capital as well as food manufacturing capital. This relation between pollution abatement capital and total capital, in addition to the pollution abatement capital information available for the U.S., were exploited to impute a

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million was spent on new PAC in the food industry. Of this amount, \$85.1 million was spent for air, \$202.6 million for water, and only \$29.1 million for solid waste.

series for pollution abatement expenditure in Canada. The main idea is to scale down the pollution abatement capital in the U.S. to estimate the pollution abatement capital series in Canada.

Assuming that: (i) capital prices in the U.S. differ from those in Canada because of differences in interest, depreciation, and tax rates; (ii) service prices of pollution abatement capital differ from service prices of general food manufacturing capital because of differences in technologies; and (iii) there is perfect competition in capital markets, we have

$$W_{k,us} / W_{k,us}^{pa} = W_{k,can} / W_{k,can}^{pa} \quad \text{(C.3)}$$

In other words, the inter-country price ratio is the same for pollution abatement capital as it is for total capital in the food manufacturing sector. The service price of the PACE series in Canada is computed by solving equation (C.3) for $W_{k,can}^{pa}$.

Similarly, the stock of pollution abatement capital in Canada was computed from:

$$K_{us,total} / K_{us,pac} = K_{can,,total} / K_{can,pac} \quad \text{(C.4)}$$

This relationship is more difficult to justify than is (C.3). However, environmental legislation was adopted in Canada about the same time that it was adopted in the United States. In addition, both countries rely heavily on standards to enforce environmental regulations, requiring firms to invest in pollution abatement technology. This might suggest that the two countries have indeed followed the same time pattern of investment in pollution abatement capital, as equation (C.4) implies.

The final step was to impute an operating cost series for Canada, assuming that the ratio of capital to non-capital pollution abatement expenditures is the same in Canada as in the U.S.:

$$(PK)_{us}^{pa} / OC_{us}^{pa} = (PK)_{can}^{pa} / OC_{can}^{pa} \quad \text{(C.5)}$$

C-3 Incorporating the Effects of Environmental Regulations in the Measure of Productivity growth and Technological Change

Denison (1979) argued that the productivity growth slowdown observed in the manufacturing industry since the 1970s, has been associated with the growth of environmental regulations during that same period. This claim is based on the idea that environmental regulations impose significant costs to firms as they conform to various environmental regulations and standards. That is, additional inputs are used in the production process, decreasing productivity and affecting the firm's ability to compete (Jaffe and al. 1995). As pointed out in Chapter 2, some have argued that environmental regulations induce firms to adopt better technology, therefore decreasing costs and improving productivity and competitiveness.

In order to assess the impact of environmental regulations in the TFPG, a pollution abatement expenditure variable is incorporated in the cost function:

$$C_e = p(Y,W,t,E) \qquad \text{(C.6)}$$

where $E = P_e K_e$ represents pollution control expenditures.

If pollution control expenditures inputs are non-joint with those which affect output, equation (C.6) can be rewritten as:

$$C_e = g(Y,W,t) + E \qquad \text{(C.7)}$$

In that case, TFPG is given by:

$$\varepsilon_{ct} = \frac{\partial \ln g}{\partial t} = \frac{d\ln C}{dt} - \sum_i S_i \frac{d\ln W_i}{dt} - \varepsilon_{cy}\frac{d\ln Y}{dt} - S_e \frac{d\ln E}{dt} \qquad \text{(C.8)}$$

where $S_e = E/C_e$.