WORKING PAPER

CAPITAL-EMBODIED TECHNICAL CHANGE AND THE PRODUCTIVITY GROWTH SLOWDOWN IN CANADA

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by Surendra Gera, Wulong Gu and Frank C. Lee,
Industry Canada

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Comments should be addressed to:

Someshwar Rao, Director
Strategic Investment Analysis
Micro-Economic Policy Analysis
Industry Canada
5th Floor, West Tower
235 Queen Street
Ottawa, Ontario
K1A 0H5
Telephone: (613) 941-8187; Fax: (613) 991-1261; e-mail: rao.someshwar@ic.gc.ca

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ABSTRACT

Previous empirical studies on productivity growth have been inconclusive in identifying the causes of the slowdown since 1973. The purpose of this study is to gain a better understanding of the causes of the slowdown by estimating the effects of capital-embodied technical change (the vintage effect) on productivity growth in Canada. In particular, we examine the implications of three issues for the slowdown. First, we examine whether the vintage effect was an important factor. Second, we investigate the implications of the "catch-up" effect for Canadian industries. Third, we analyse the impact of growth in the capital-labour ratio on Canadian industries. We find that there is significant and robust evidence of the vintage effect across Canadian industries, explaining, on average, about 14 per cent of the slowdown in total factor productivity growth and about 7 per cent of the slowdown in labour productivity growth since 1973. The vintage effect was driven mainly by a slowdown in the rate of technical progress embodied in the capital stock, particularly in machinery and equipment. We also find that the catch-up effect, although an important source of productivity growth, was not an important factor behind the slowdown. Finally, we find that in contrast to the evidence in other major industrialized economies, the rate of growth of the capital-labour ratio in Canada increased in almost all industries since 1973. This has an implication of increasing rather than decreasing labour productivity growth. We also find evidence of complementarity between capital accumulation and technological advances. Through this avenue, capital accumulation enables Canadian industries to catch up to the productivity levels of their U.S. counterparts. We interpret this as additional support for the embodiment hypothesis.

1. INTRODUCTION

Stagnant living standards in the industrialized countries can ultimately be attributed to the slowdown in productivity growth since 1973. Indeed, this slowdown has been one of the major economic concerns shared by policy makers in the major economies of the Organization for Economic Co-operation and Development (OECD). In Canada, labour productivity in the business sector grew at an average rate of 2.9 per cent over the period from 1960 to 1973. However, from 1973 through 1996, average annual labour productivity growth decreased to 1.1 per cent. Similarly, in the United States labour productivity growth declined from 2.6 per cent per annum in 1960–73 to 0.7 per cent per annum in 1973–96 (OECD, 1997).

Previous empirical studies on Canadian productivity growth have been inconclusive in identifying the causes of the slowdown. The suggested causes include: slower growth in research and development (R&D) intensity; a slowdown in infrastructure spending; a lack of technological progress in several mature industries; inter-sectoral shifts of output and labour toward services; and reduced importance of the "catch-up" bonus (see, for example, Daly and Rao, 1985; Denny et al., 1992; Rao and Lemprière, 1992; Morrison, 1992; Mullen and Williams, 1994; and Fuss and Van den Berg ,1995).[1] As a possible explanation of the slowdown, however, none of these studies considered the "vintage effect," which states that new capital is more productive than old capital per (constant) dollar of expenditure.

A recent study by Wolff (1996) found that the vintage effect was a strong determinant of the post-1973 productivity growth slowdown in OECD countries. Using data from 1950 to 1989 for six OECD countries (France, Germany, Japan, the Netherlands, the U.K., and the United States), Wolff found that the vintage effect, estimated by changes in the average age of the total capital stock (structures, machinery and equipment), explained on average about 40 per cent of the slowdown.[2] Other factors that he found contributed to the slowdown included: the slowdown in the growth of the capital-labour ratio, which accounted for another 36 per cent; the deceleration in GDP growth, which explained 25 per cent; and the diminution of the catch-up effect, which accounted for only 3.6 per cent. Thus the unexplained portion of the slowdown was only 5 per cent.[3]

Two other recent studies (Hulten, 1992; and Abramovitz, 1994) using a growth-accounting framework also confirmed the importance of capital-embodied technical change for U.S. productivity growth. Hulten estimated that approximately 20 per cent of total technical change in U.S. manufacturing over the period from 1949 to 1983 could be ascribed to embodied technical change in machinery and equipment. In this methodology, the embodiment effect is estimated directly, from real quality–adjusted (hedonic) price movements of machinery and equipment components, rather than from the age of the capital stock. Abramovitz estimated that, on average about 16 per cent of the productivity growth slowdown between 1950–73 and 1973–84 could be attributed to the change in the average age of capital.[4]

In this study, we investigate whether the vintage effect has played an important role in the post-1973 productivity growth slowdown in Canada.[5] In particular, we consider three factors to explain the slowdown: the vintage effect, the catch-up effect and the growth of the capital-labour ratio.

- First, the *vintage effect* or the embodiment hypothesis suggests that new capital is more productive than older capital because new capital is more likely to embody best-practice technologies. Accordingly, as a country's capital stock ages, there is a negative implication for productivity performance. This study examines whether embodied technical change (the vintage effect) can be adduced as an explanation of the productivity growth slowdown in Canada.
- Second, the recent economic literature suggests that the *catch-up effect* is an important factor in economic growth. The catch-up effect assumes that technology diffuses from more technologically advanced countries to laggards. In this paper, the catch-up effect implies that industries in countries that lag furthest behind the industries in leading countries in terms of technology level should exhibit the most rapid rate of growth in output. This is a novel feature of this study as most of the convergence literature examines the catch-up hypothesis at the aggregate economy-wide level rather than at the industry level.[6]
- Third, we consider the implications of *growth in the capital-labour ratio* across Canadian industries for the productivity growth slowdown.

Our analysis is based mainly on Statistics Canada's KLEMS data base, with observations on each of the 22 industries in the Canadian business sector over the period 1963–92.

Our results can be summarized as follows:

- The vintage effect appears to have played a significant role, explaining on average about 14 per cent of the TFP growth slowdown and 7 per cent of the post-1973 labour productivity growth slowdown in Canada. The effect is mainly driven by the slowdown in the rate of capital-embodied technical progress after 1973. This slowdown was much more pronounced in machinery and equipment (M&E) than in non-residential structures.
- The catch-up effect, although an important source of productivity growth, was not an important factor behind the productivity growth slowdown.
- There exists a significant complementary relationship between capital accumulation and technological advances. That is, capital accumulation accelerates the catch-up process as newer capital equipment, embodying advanced technology, is applied in the production process.
- The rate of growth of the capital-labour ratio increased in almost all industries in our sample after 1973, contributing to increases rather than declines in labour productivity growth.

The next section of the paper presents the empirical model used to estimate the embodiment effect and its role in explaining the slowdown in productivity growth in

Canadian industries. The following section presents data and key summary statistics used in the empirical analysis. The section entitled “Empirical Analysis” presents our regression results. “Sources of Productivity Slowdown” analyses the relative importance of each factor in the productivity growth slowdown in Canadian industries since 1973, by decomposing productivity growth on the basis of the empirical results. Concluding remarks are presented in the last section.

2. EMPIRICAL MODEL

According to Solow (1960), "Many, if not most, innovations need to be embodied in new kinds of durable equipment before they can be made effective." This idea behind embodied technological progress has a long history in economics. However, Johansen (1959) and Solow (1960) were the first to formally describe the embodiment hypothesis. Their models form a basis for most empirical frameworks used to study embodied technological change.

We adopt a commonly used Cob-Douglas production function where output, *Y(vat)*, is assumed to depend on $K(v,t)$, the capital of vintage *v* that survives at time *t*, on $L(v,t)$, the amount of labour employed at time *t* on the capital of vintage *v*, and on $X(v,t)$, the amount of intermediate goods and services employed at time *t* on the capital of vintage *v*. We introduce the total factor productivity (TFP) gap, τ, in the production function to identify the technological catch-up possibilities for Canadian industries relative to U.S. industries.

Assuming constant returns to scale,[7] the production function that applies to capital of vintage *v* can be written as:

(1) $$Y(v,t) = Ae^{\mu t}(e^{\lambda t}K(v,t))^{\alpha}\, L(v,t)^{\beta}\, X(v,t)^{1-\alpha-\beta}\, e^{\gamma\tau t}$$

where μ is the rate of disembodied technological change; λ is the rate of capital-embodied technological change (the exponential rate of growth of output over the successive vintages of capital); α is the elasticity of output with respect to capital; β is the elasticity of output with respect to labour; $1-\alpha-\beta$ is the elasticity of output with respect to intermediate goods and services; and γ is the rate of the catch-up effect.

Total output $Y(t)$ of an industry at time *t*, obtained by adding up output stemming from all vintages of capital stock, is expressed as follows:

(2) $$Y(t) = \left[\int_{-\infty}^{t} Y(v,t)dv\right]e^{\gamma\tau t}$$

Following Solow (1960), it can be shown that total gross output can be expressed as a function of the effective capital stock, $J(t)$, total amount of labour, $L(t)$, and total amount of intermediate goods and services, $X(t)$, employed by all vintages of capital:

(3) $$Y(t) = Ae^{\mu t}J(t)^{\alpha}\, L(t)^{\beta}\, X(t)^{1-\alpha-\beta}\, e^{\gamma\tau t}$$

where the effective stock of capital is defined as a weighted sum of surviving vintages of capital, with a smaller weight given to older capital stock, on the basis of the rate of embodied technical progress. Specifically, the effective capital stock is

$$(4) \qquad J(t) = \int_{-\infty}^{t} e^{\lambda t} K(v,t) dv$$

Using Nelson's (1964) approximation formula, the effective capital stock at time t can be written as

$$(5) \qquad J(t) = Be^{\lambda t} K(t) e^{-\lambda G(t)}$$

where $K(t)$ is the gross capital stock and $G(t)$ is the average age of the gross capital stock at time t.

Substituting equation (5) into equation (3) and expressing the resulting equation as output per unit of labour yields

$$(6) \qquad Y(t)/L(t) = Ce^{(\mu+\alpha\lambda)t - \alpha\lambda G(t)} \left(K(t)/L(t)\right)^{\alpha} \left(X(t)/L(t)\right)^{1-\alpha-\beta} e^{\gamma\tau t}$$

where the parameter C equals AB^{α}.

Taking the logarithms of equation (6) and adding an error term yields the basic estimation equation

$$(7) \qquad \ln(Y/L)_{it} = a_i + a_1 t + a_2 G_{it} + a_3 \ln(K/L)_{it} + a_4 \ln(X/L)_{it} + a_5 \tau t + \varepsilon_{it}$$

where subscript i is an index for industry i, $a_1 = \mu + \alpha\lambda$, $a_2 = -\alpha\lambda$, $a_3 = \alpha$, $a_4 = 1 - \alpha - \beta$, and $a_5 = \gamma$.

The catch-up variable is defined as the product of time trend, t, and the TFP gap, τ, (calculated as the percentage difference between TFP levels in Canadian and U.S. industries). The productivity catch-up hypothesis simply states that the further Canadian industries lag behind their U.S. counterparts in technology, the more opportunities there are for Canadian industries to imitate and purchase advanced technologies and thus enhance productivity growth (Gerschenkron, 1952; Kuznets, 1973). However, being backward does not guarantee that industries will catch up automatically; other factors have to be present. One such factor is capital accumulation (Wolff, 1991). Wolff argues that substantial capital accumulation is necessary to put new inventions into practice and affect employment. This association is often referred to as the "embodiment effect": some technological innovation is embodied in capital.[8] To investigate the role of capital accumulation in the catch-up process, we introduce an interaction term between the catch-up variable and the logarithm of the capital-labour ratio, $\left(\tau t \ln(K/L)\right)_{it}$.

In our empirical analysis, we use the average values of the TFP gap over the preceding three years to reduce any random disturbances in industry TFPs.[9] To control for the well-known cyclical fluctuations in labour productivity, we introduce industry capacity utilization rates, CU_{it}, in equation (7). The logarithm of R&D capital stock, $ln(R)_{it}$, is also introduced to account for the impact of research and development on industry productivity.

Empirical specification of equation (7) introducing the above additional variables[10] becomes:

$$\text{(8)} \quad \ln(Y/L)_{it} = a_i + a_1 t + a_2 G_{it} + a_3 \ln(K/L)_{it} + a_4 \ln(X/L)_{it} + a_5 \tau t + a_6 \left(\tau t \ln(K/L)\right)_{it} + a_7 CU_{it} + a_8 \ln(R)_{it} + \varepsilon_{it}.$$

3. DATA AND BASIC STATISTICS

The empirical analysis is performed on a panel of 22 industries from the entire Canadian business sector over the period from 1963 to 1992. The main data sources are Statistics Canada's KLEMS data base, the Fixed Capital Flows and Stocks data and the OECD's International Sectoral Data Base (ISDB).

Total gross output, capital (*K*), labour (*L*), energy (*E*), material (*M*) and services (*S*) over the 1961–92 period are obtained from the KLEMS data base. We aggregate energy, material and service inputs into one broad category of intermediate goods and services, using the Tornqvist formula.[11] Gross output, labour input, and intermediate goods and services are also aggregated to 22 industries from 127 industries, using the Tornqvist formula.[12]

Data on the gross capital stock and its age are obtained from the Fixed Capital Flows and Stocks data. Gross capital stock is estimated using a perpetual inventory method based on a random discard pattern around a declining service life[13] (on the basis of the information collected in the Annual Survey of Capital and Repair Expenditures). For example, the service life of building construction declined from 38 years in 1971 to 37 years in 1994. Over the same period, the service life declined from 36 to 30 years for engineering construction, and from 15 to 11 years for machinery and equipment.[14] The average age of the gross capital stock is then estimated as the weighted sum of the ages of surviving capital of all vintages, using surviving capital as weights.

The data used to calculate TFP gaps between Canadian and U.S. industries are obtained from the ISDB, supplemented with the data from CANSIM for a number of Canadian industries.[15] As discussed earlier, the TFP gap is measured by the percentage difference between the TFP level in a Canadian industry and its counterpart in the United States, where the total factor productivity level (TFP_{it}) of industry i at time t is calculated as

(10) $$ln(TFP_{it}) = \alpha\, ln\left(Q_{it}/L_{it}\right) + (1-\alpha)\, ln\left(Q_{it}/K_{it}\right)$$

Here Q_{it} denotes the value added converted to U.S. dollars using the OECD 1985 purchasing power parities (PPPs). Similarly, K_{it} denotes the gross capital stock in 1985 PPPs (U.S. dollars), L_{it} denotes total employment and α denotes labour share.[16]

The data on capacity utilization by industry are obtained from CANSIM (Statistics Canada, Catalogue 31-003). Unfortunately, the data are not available for a number of service industries in our sample.[17] Consequently, we use the capacity utilization rate for total non–farm goods producing industries as a proxy for the capacity utilization rate for these service industries. Finally, the R&D capital stock data are estimated using a perpetual inventory method.[18]

We now turn to the basic data from our regression analysis (Tables 1 to 7).

Table 1
Labour productivity[1]

	Labour productivity (1986 K$ per hour)			Annual rate of growth (%)	
Industry (ISIC Rev. 2)	**1963**	**1973**	**1992**	**1963–73**	**1973–92**
1. Agriculture, forestry & fishery	10.46	17.17	29.49	4.96	2.85
2. Mining & quarrying	65.95	112.87	134.26	5.37	0.91
3. Food, beverages & tobacco	56.48	77.98	105.37	3.23	1.58
4. Textiles, apparel & leather	16.73	26.13	41.24	4.46	2.40
5. Wood products & furniture	26.06	36.21	58.34	3.29	2.51
6. Paper, paper products & printing	42.01	57.30	72.22	3.10	1.22
7. Chemicals[2]	78.46	120.14	138.66	4.26	0.75
8. Non-metallic mineral products	39.52	58.27	66.30	3.88	0.68
9. Basic metal industries	62.33	83.17	129.39	2.88	2.33
10. Metal products	32.34	45.62	54.38	3.44	0.93
11. Agricultural & industrial machinery	26.34	39.09	74.70	3.95	3.41
12. Electrical goods	26.11	39.30	81.30	4.09	3.83
13. Transportation equipment	46.45	84.17	122.74	5.95	1.99
14. Other manufacturing industries	27.36	40.87	44.58	4.01	0.46
15. Electricity, gas & water	50.81	85.14	111.37	5.16	1.41
16. Construction	35.24	45.17	57.07	2.48	1.23
17. Wholesale and retail trade	15.32	19.03	24.31	2.17	1.29
18. Restaurants and hotels	21.52	24.42	21.99	1.26	-0.55
19. Transport & storage	20.26	35.02	50.16	5.47	1.89
20. Communications	16.62	30.38	89.49	6.03	5.69
21. FIRE & business services	42.90	50.86	63.96	1.70	1.21
22. Community, social & personal services	24.63	27.30	30.13	1.03	0.52

1 Labour productivity is measured by gross output per hour worked.
2 Chemicals & chemical petroleum, coal, rubber & plastic products.

Table 1 presents labour productivity levels for three selected years (1963, 1973 and 1992), and average annual labour productivity growth for the two periods of 1963–73 and 1973–92. It shows the well-known slowdown in labour productivity growth since 1973. The level of labour productivity, measured by gross output (in 1986 constant dollars)[19] per worker-hour, shows a substantial variation across industries. In 1992, labour productivity ranges from a high of $138.66 per hour in the chemicals, chemical petroleum, coal, rubber and plastics industries, to a low of $21.99 per hour in restaurants and hotels. Overall, the labour productivity level is lower in services than in manufacturing industries.

Table 2
Average age of gross capital stock (years)

	Average age			Annualized change	
Industry (ISIC Rev. 2)	**1963**	**1973**	**1992**	**1963–73**	**1973–92**
1. Agriculture, forestry & fishery	11.01	10.33	11.58	-0.07	0.07
2. Mining & quarrying	7.34	8.14	9.11	0.08	0.05
3. Food, beverages & tobacco	12.74	12.14	11.29	-0.06	-0.04
4. Textiles, apparel & leather	14.46	11.44	10.76	-0.30	-0.04
5. Wood products & furniture	12.53	9.04	8.93	-0.35	-0.01
6. Paper, paper products & printing	13.46	10.85	9.11	-0.26	-0.09
7. Chemicals[1]	11.26	10.58	10.92	-0.07	0.02
8. Non-metallic mineral products	11.22	10.14	10.13	-0.11	-0.00
9. Basic metal industries	10.45	10.97	10.82	0.05	-0.01
10. Metal products	12.34	11.38	10.62	-0.10	-0.04
11. Agricultural & industrial machinery	12.28	10.72	9.21	-0.16	-0.08
12. Electrical goods	9.73	9.64	8.07	-0.01	-0.08
13. Transportation equipment	13.09	10.32	7.60	-0.28	-0.14
14. Other manufacturing industries	12.19	10.64	9.43	-0.16	-0.06
15. Electricity, gas & water	13.68	13.82	15.64	0.01	0.10
16. Construction	6.71	6.61	6.53	-0.01	-0.00
17. Wholesale and retail trade	13.48	13.54	11.18	0.01	-0.12
18. Restaurants and hotels	17.99	16.07	9.83	-0.19	-0.33
19. Transport & storage	21.74	19.08	17.20	-0.27	-0.10
20. Communications	14.04	12.13	10.99	-0.19	-0.06
21. FIRE & business services	15.85	11.55	9.91	-0.43	-0.09
22. Community, social & personal services	12.97	12.26	16.49	-0.07	0.22

1 Chemicals and chemical petroleum, coal, rubber and plastic products.

Table 2 shows that the average age of the gross capital stock declined over the 1963–73 period in almost all industries except four: mining and quarrying; basic metal; electricity, gas and water; and wholesale and retail trade. The age of the capital stock in these industries experienced a negligible increase. However, the trend toward younger capital either reversed or slowed down in most industries during the 1973–92 period. This turnaround in the age of the capital stock after 1973 already points to the embodiment effect as a possible cause of the slowdown in productivity growth.

In Tables 3 and 4, the average age of the total gross capital stock is disaggregated into two components: machinery and equipment, and non-residential structures. The pattern of changes in the age of machinery and equipment generally mirrors that for the total capital stock (Table 3). During the 1963–73 period, the age of M&E declined in almost all industries. Only three service industries — transport and storage; communications; and community, social and personal services — showed a slight increase in the age of M&E. For the period 1973–92, capital accumulation in M&E decelerated in almost all industries except service industries, causing the reduction in the age of M&E to either reverse or slow down. For most service industries, the age of M&E actually declined at a faster rate in 1973–92 than in 1963–73.

Not surprisingly, we find that the age of non-residential structures exceeded the age of M&E (Table 4), reflecting a longer service life of structures. Unlike the age of M&E, which declined in most industries (though at a slower rate after 1973), the age of non-residential structures showed a continuous increase from 1973 through 1985 and then to 1992.

Table 3
Average age of machinery and equipment (years)

	Average age			Annualized change	
Industry (ISIC Rev. 2)	**1963**	**1973**	**1992**	**1963–73**	**1973–92**
1. Agriculture, forestry & fishery	6.55	5.60	5.82	-0.10	0.01
2. Mining & quarrying	7.19	6.11	6.34	-0.11	0.01
3. Food, beverages & tobacco	9.21	8.48	6.50	-0.07	-0.10
4. Textiles, apparel & leather	9.98	7.44	5.68	-0.25	-0.09
5. Wood products & furniture	9.04	6.88	6.69	-0.22	-0.01
6. Paper, paper products & printing	8.62	8.55	7.25	-0.01	-0.07
7. Chemicals[1]	8.27	7.96	7.20	-0.03	-0.04
8. Non-metallic mineral products	7.91	8.25	7.61	0.03	-0.03
9. Basic metal industries	8.31	8.49	8.35	0.02	-0.01
10. Metal products	8.52	6.52	6.01	-0.20	-0.03
11. Agricultural & industrial machinery	7.35	6.13	4.30	-0.12	-0.10
12. Electrical goods	7.64	6.05	4.55	-0.16	-0.08
13. Transportation equipment	9.61	7.30	5.21	-0.23	-0.11
14. Other manufacturing industries	5.59	5.49	4.52	-0.01	-0.05
15. Electricity, gas & water	11.48	9.93	9.72	-0.16	-0.01
16. Construction	5.86	5.27	5.24	-0.06	-0.00
17. Wholesale and retail trade	6.97	6.16	4.24	-0.08	-0.10
18. Restaurants and hotels	4.79	4.07	3.42	-0.07	-0.03
19. Transport & storage	10.82	11.22	8.08	0.04	-0.16
20. Communications	8.54	8.71	7.09	0.02	-0.09
21. FIRE & business services	4.59	3.95	3.33	-0.06	-0.03
22. Community, social & personal services	6.03	6.05	4.17	0.00	-0.10

1 See note 1, Table 2.

Table 4
Average age of non-residential structures (years)

	Average age			Annualized change	
Industry (ISIC Rev. 2)	**1963**	**1973**	**1992**	**1963–73**	**1973–92**
1. Agriculture, forestry & fishery	14.70	14.52	14.99	-0.02	0.02
2. Mining & quarrying	7.38	8.48	9.44	0.11	0.05
3. Food, beverages & tobacco	16.56	15.96	18.64	-0.06	0.14
4. Textiles, apparel & leather	21.63	17.57	19.92	-0.41	0.12
5. Wood products & furniture	16.75	12.49	13.90	-0.43	0.07
6. Paper, paper products & printing	20.88	15.24	15.56	-0.56	0.02
7. Chemicals[1]	12.85	11.83	14.55	-0.10	0.14
8. Non-metallic mineral products	15.27	13.15	15.96	-0.21	0.15
9. Basic metal industries	13.83	15.48	16.23	0.16	0.04
10. Metal products	16.24	17.36	17.32	0.11	-0.00
11. Agricultural & industrial machinery	15.79	13.72	15.48	-0.21	0.09
12. Electrical goods	12.05	13.14	15.58	0.11	0.13
13. Transportation equipment	17.35	14.54	13.97	-0.28	-0.03
14. Other manufacturing industries	15.44	13.87	15.57	-0.16	0.09
15. Electricity, gas & water	13.97	14.48	18.15	0.05	0.19
16. Construction	10.37	12.48	10.16	0.21	-0.12
17. Wholesale and retail trade	15.75	16.27	16.81	0.05	0.03
18. Restaurants and hotels	19.05	17.75	15.80	-0.13	-0.10
19. Transport & storage	25.17	21.67	20.87	-0.35	-0.04
20. Communications	18.62	15.38	15.13	-0.32	-0.01
21. FIRE & business services	16.46	12.08	12.38	-0.44	0.02
22. Community, social & personal services	13.34	12.66	19.35	-0.07	0.35

1 See note 1, Table 2.

Table 5 presents capital intensity (the ratio of gross capital stock to hours worked) in three selected years (1963, 1973, 1992) and its annual average growth rates for the two periods of 1963–73 and 1973–92. The growth in capital intensity increased in 17 out of 22 industries[20] between the periods of 1963–73 and 1973–92, despite the productivity growth slowdown. This suggests that the post-1973 slowdown in productivity growth in Canada could not be ascribed to the changes in growth of capital intensity. There was, however, a modest decline in the growth of capital intensity over the period 1972–79 (not shown in the table).

Wolff (1996) found that growth in the capital-labour ratio slowed down after 1973 in other major industrialized economies (France, Germany, Japan, the Netherlands, the United Kingdom and the United States), accounting for about 36 per cent of the post-1973 productivity slowdown in those countries. The acceleration in the growth of the capital-labour ratio in Canada after 1973 is in sharp contrast to the slowdown in the growth of this ratio in other major industrialized countries.

Table 5
Ratio of gross capital to hours worked

Industry (ISIC Rev. 2)	Gross capital-labour ratio (1986 K$ per hour)			Annual rate of growth (%)	
	1963	1973	1992	1963–73	1973–92
1. Agriculture, forestry & fishery	23.55	40.76	47.44	5.49	0.80
2. Mining & quarrying	127.52	219.90	539.70	5.45	4.73
3. Food, beverages & tobacco	21.67	30.04	54.18	3.27	3.10
4. Textiles, apparel & leather	9.43	10.55	19.73	1.13	3.29
5. Wood products & furniture	15.19	17.79	38.03	1.58	4.00
6. Paper, paper products & printing	42.37	57.16	125.36	2.99	4.13
7. Chemicals[1]	63.77	83.05	177.14	2.64	3.99
8. Non-metallic mineral products	25.25	38.42	82.14	4.20	4.00
9. Basic metal industries	61.78	82.38	217.64	2.88	5.11
10. Metal products	14.74	17.40	25.77	1.66	2.07
11. Agricultural & industrial machinery	9.82	12.54	30.55	2.44	4.69
12. Electrical goods	9.45	11.41	31.73	1.89	5.38
13. Transportation equipment	20.92	22.80	57.79	0.86	4.89
14. Other manufacturing industries	7.94	10.62	22.68	2.92	3.99
15. Electricity, gas & water	487.31	617.58	1009.18	2.37	2.58
16. Construction	5.43	6.01	13.51	1.02	4.26
17. Wholesale and retail trade	10.02	9.42	11.68	-0.62	1.13
18. Restaurants and hotels	9.62	11.49	27.31	1.77	4.56
19. Transport & storage	62.66	86.17	137.17	3.19	2.45
20. Communications	125.75	156.92	303.06	2.21	3.46
21. FIRE & business services	26.50	36.60	112.10	3.23	5.89
22. Community, social & personal services	26.07	34.46	65.11	2.79	3.35

1 See note 1, Table 2.

To examine the causes of the post-1973 acceleration in capital-labour ratio growth, Table 6 decomposes growth into capital and labour growth. It reveals that capital accumulation declined between the 1963–73 and 1973–92 periods in most industries, and especially for manufacturing industries. However, employment growth (in terms of worker-hours) experienced an even bigger decline than capital growth after 1973, leading to an increase in the growth rate of the capital-labour ratio for almost all industries.

Finally, Table 7 presents total factor productivity levels in Canadian industries relative to U.S. industries for four selected years: 1963, 1973, 1985 and 1991. Overall, Canada lagged behind the United States in terms of total factor productivity level in almost all industries, reflecting a relatively lower level of production efficiency in these Canadian industries.[21] The period from 1963 to 1973 witnessed a substantial catch-up for most Canadian industries. However, the rate of catch-up was much slower in most

Canadian industries during the period 1973–85. After 1985, the TFP gap with U.S. industries widened in all Canadian manufacturing industries. Only one primary industry (agriculture, forestry and fishery) and three service industries (wholesale and retail trade; communications; and community, social and personal services) improved their TFP positions relative to U.S. industries for the 1985–92 period. In sum, the data in Table 7 generally support the catch-up hypothesis and show that much of the catch-up for Canadian industries occurred before 1973.

Table 6
Decomposition of the growth rate of the capital-labour ratio (per cent per year)

	Growth in capital to hours			Growth in capital			Growth in hours		
Industry (ISIC Rev. 2)	**1963–73**	**1973–92**	**Change**	**1963–73**	**1973–92**	**Change**	**1963–73**	**1973–92**	**Change**
1. Agriculture, forestry & fishery	5.49	0.80	-4.69	2.47	-0.05	-2.52	-3.02	-0.85	2.17
2. Mining & quarrying	5.45	4.73	-0.72	7.45	4.72	-2.73	2.01	-0.00	-2.01
3. Food, beverages & tobacco	3.27	3.10	-0.16	3.44	2.76	-0.68	0.17	-0.35	-0.52
4. Textiles, apparel & leather	1.13	3.29	2.17	1.21	0.74	-0.47	0.08	-2.55	-2.64
5. Wood products & furniture	1.58	4.00	2.42	3.70	3.35	-0.35	2.12	-0.65	-2.77
6. Paper, paper products & printing	2.99	4.13	1.14	4.55	4.32	-0.23	1.55	0.18	-1.37
7. Chemicals[1]	2.64	3.99	1.34	5.09	4.70	-0.39	2.45	0.71	-1.74
8. Non-metallic mineral products	4.20	4.00	-0.20	6.04	2.60	-3.44	1.85	-1.39	-3.24
9. Basic metal industries	2.88	5.11	2.24	4.84	3.55	-1.29	1.97	-1.56	-3.53
10. Metal products	1.66	2.07	0.41	4.01	1.43	-2.58	2.35	-0.64	-2.99
11. Agricultural & industrial machinery	2.44	4.69	2.25	5.53	5.06	-0.47	3.09	0.37	-2.71
12. Electrical goods	1.89	5.38	3.49	4.23	4.58	0.35	2.34	-0.80	-3.14
13. Transport. equipment	0.86	4.89	4.03	5.20	5.37	0.17	4.33	0.48	-3.86
14. Other manufacturing industries	2.92	3.99	1.07	4.76	4.19	-0.58	1.85	0.19	-1.65
15. Electricity, gas & water	2.37	2.58	0.22	5.89	5.17	-0.72	3.52	2.59	-0.94
16. Construction	1.02	4.26	3.24	2.91	4.87	1.96	1.90	0.61	-1.29
17. Wholesale and retail trade	-0.62	1.13	1.75	2.46	2.89	0.43	3.07	1.75	-1.32
18. Restaurants and hotels	1.77	4.56	2.79	6.13	8.30	2.18	4.35	3.74	-0.61
19. Transport & storage	3.19	2.45	-0.74	4.13	2.82	-1.32	0.95	0.37	-0.58
20. Communications	2.21	3.46	1.25	4.79	4.60	-0.19	2.57	1.13	-1.44
21. FIRE & business services	3.23	5.89	2.66	7.58	8.90	1.32	4.35	3.01	-1.34
22. Community, social & personal services	2.79	3.35	0.56	9.84	8.21	-1.63	7.05	4.86	-2.18

1 See note 1, Table 2.

Table 7
Total factor productivity levels in Canada relative to the United States

Industry (ISIC Rev. 2)	1963	1973	1985	1991
1. Agriculture, forestry & fishery	0.95	1.04	0.81	0.90
2. Mining & quarrying	1.06	1.18	0.84	0.70
3. Food, beverages & tobacco	0.87	0.95	0.88	0.84
4. Textiles, apparel & leather	0.75	1.04	0.99	0.83
5. Wood products & furniture	0.59	0.72	0.82	0.73
6. Paper, paper products & printing	0.57	0.66	0.73	0.64
7. Chemicals[1]	0.50	0.62	0.65	0.60
8. Non-metallic mineral products	0.73	1.05	0.92	0.77
9. Basic metal industries	0.55	0.68	0.88	0.76
10. Metal products	1.01	0.89	0.91	0.80
11. Agricultural & industrial machinery	0.62	0.66	0.89	0.75
12. Electrical goods	1.17	1.26	1.10	0.79
13. Transportation equipment	0.45	0.82	0.89	0.83
14. Other manufacturing industries	0.75	0.78	0.74	0.59
15. Electricity, gas & water	0.45	0.48	0.59	0.46
16. Construction	0.49	0.82	1.10	1.07
17. Wholesale and retail trade	0.63	0.78	0.84	0.87
18. Restaurants and hotels	1.32	1.43	1.03	0.70
19. Transport & storage	0.39	0.49	0.71	0.59
20. Communications	0.37	0.47	0.53	0.58
21. FIRE & business services	0.87	0.78	0.81	0.78
22. Community, social & personal services	0.50	0.53	0.64	0.76

1 See note 1, Table 2.

4. EMPIRICAL ANALYSIS

We present our empirical results in two parts: first, some raw correlations, and then regression results.

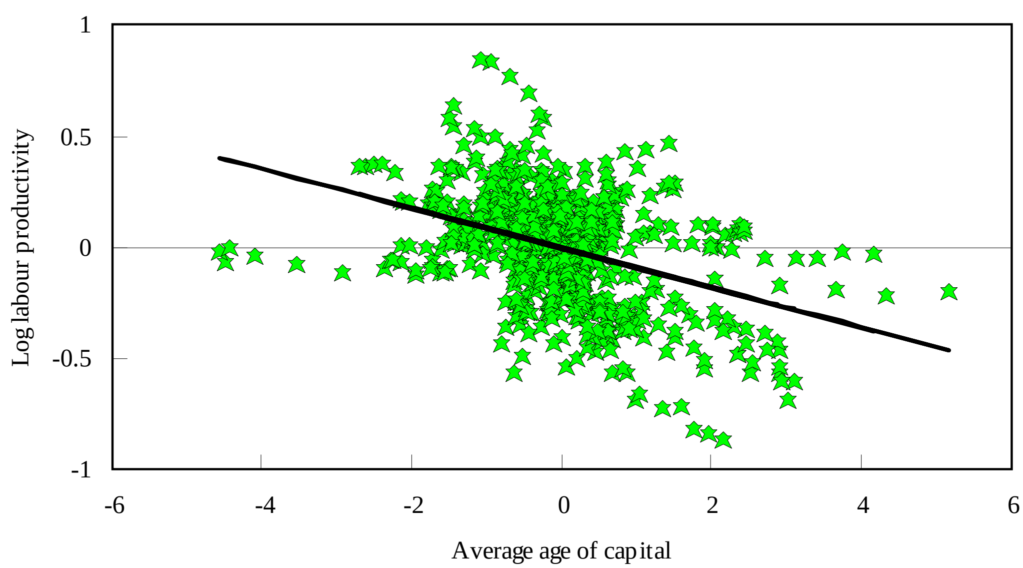
Raw Correlation

Some raw empirical correlations relevant to the embodiment effect and the catch-up hypothesis are presented in Figures 1 to 4. The figures present a partial scatter of log labour productivity against the average age of the total gross capital stock, the average age of machinery and equipment, the average age of non-residential structures, and the catch-up variable respectively. All these figures control for industry fixed effects by plotting deviations of log labour productivity around its industry means against the deviations of an explanatory variable around the industry means. The figures plot annual data over the 1963–92 period for 22 industries.

Figure 1 shows a strong and significant vintage effect: younger capital stock is associated with faster labour productivity growth. This relationship becomes stronger for M&E, as shown in Figure 2. However, Figure 3 indicates that there is little evidence of embodiment effects in productivity growth for non-residential structures.

Figure 4 provides a scatter of log labour productivity against the catch-up variable. The plot shows a strong catch-up effect: faster productivity growth is associated with industries having larger TFP gaps vis-à-vis the United States.

Figure 1
Labour Productivity and Age of Capital Stock
Coef = -0.089; t = -11.49



The four figures point to the significance of the embodiment and catch-up effects for productivity growth. We now turn to our regression results to measure the vintage effect and the catch-up effect.

Figure 2
Labour Productivity and Age of Machinery and Equipment
Coef = -0.210; t = -22.88

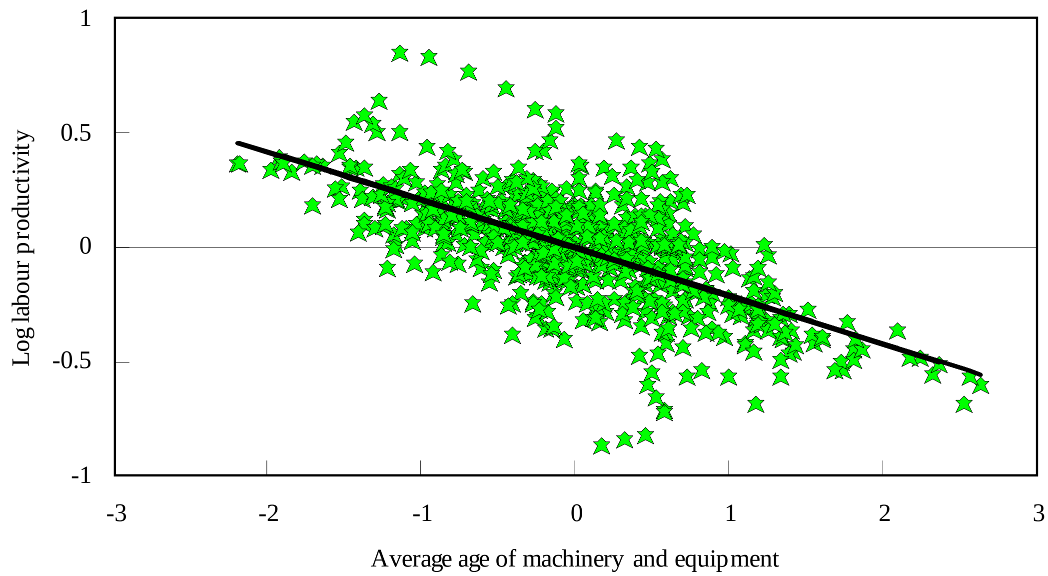


Figure 3
Labour Productivity and Age of Non-Residential Structures
Coef = -0.012; t = -1.59

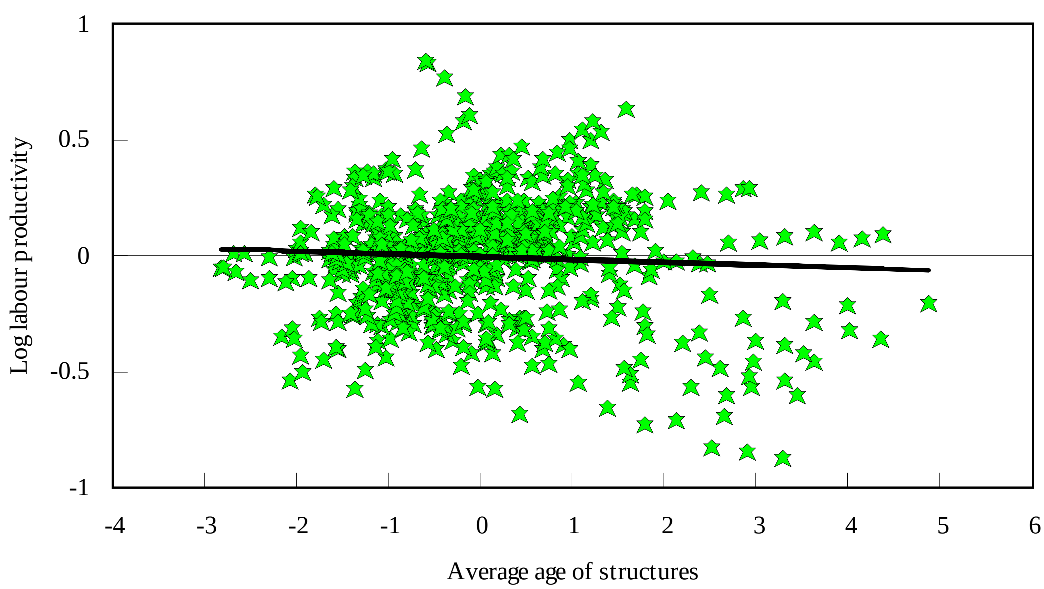
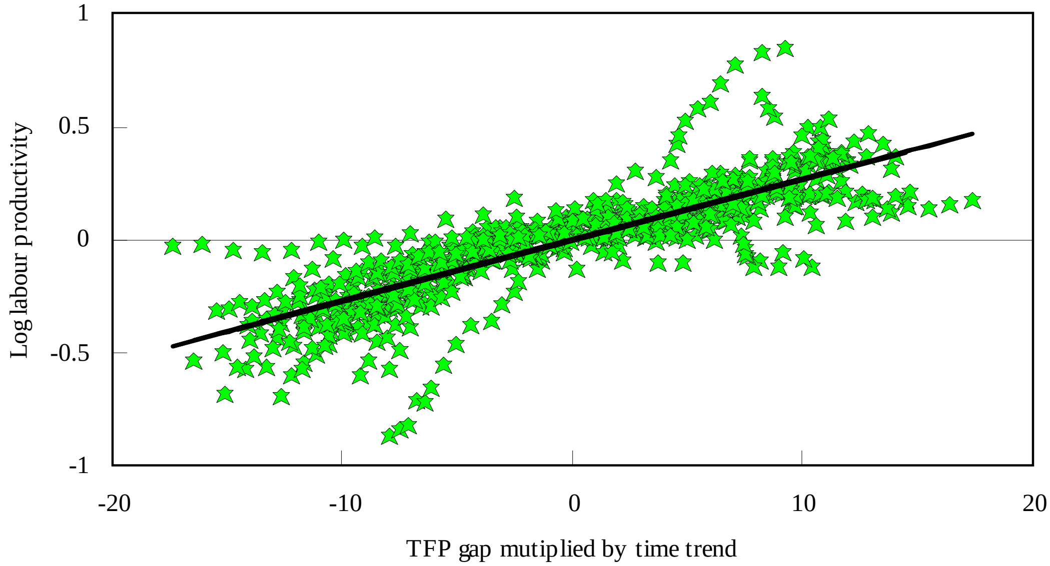


Figure 4
Labour Productivity and TFP Gap
Coef = 0.027; t = 38.82



Regression Analysis

In the following empirical analysis,[22] our major interest lies in three variables. The first and most important is the vintage effect, i.e., the significance of the embodiment hypothesis for productivity growth across Canadian industries. The second is the catch-up variable: to what extent has the catch-up effect contributed to productivity growth in Canada? The third is the growth of the capital-labour ratio: did this contribute to productivity growth across Canadian industries?

Before presenting regression results, one preliminary issue must be discussed concerning the non-stationarity of the variables used in the regression equations. Table A1 in the Appendix reports the results from pooled unit root tests on the null hypothesis that the time series for each industry is non-stationary against the alternative hypothesis that each time series is stationary. The pooled unit root test statistics on a time series are obtained from a regression that includes the time trend, the lagged first difference of the variable and industry dummies. These test statistics are then compared with the critical values in Table 5 in Levin and Lin (1992).[23] The unit root tests indicate that the following variables are non-stationary: the logarithm of labour productivity, the logarithm of the capital-labour ratio, the logarithm of the ratio of intermediate goods and services to labour, the catch-up variable, the catch-up variable interacted with the logarithm of the capital-labour ratio, and the logarithm of R&D capital stock. In contrast, the average age of total capital stock, the average age of machinery and equipment, the average age of non-residential structures, and capacity utilization rates are stationary.

Given the non-stationarity of variables in our regression equations, we test for co-integration. The test statistics for all six specifications in Table 8 indicate that the null hypothesis of non-stationarity of the residuals can be rejected at the 5-per-cent level.[24]

Table 8
Regression results: 1963–92[1]
(Dependent variable: Log of labour productivity (gross output / hours worked)

Independent variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Constant	-0.6998	-0.6065	-0.7230	-0.6473	-0.7715	-0.7214
	(7.60)	(7.02)	(7.63)	(7.13)	(7.96)	(7.85)
Time trend	0.0025	0.0027	0.0027	0.0028	0.0065	0.0060
	(5.05)	(5.78)	(5.34)	(5.45)	(10.39)	(7.88)
Time trend* dummy for primary industries	-0.0065	-0.0061	-0.0074	-0.0069	-0.0058	-0.0058
	(4.28)	(3.72)	(4.86)	(4.10)	(3.54)	(3.45)
Time trend* dummy for service industries	-0.0034	-0.0037	-0.0045	-0.0050	-0.0044	-0.0042
	(5.44)	(5.47)	(7.92)	(8.14)	(7.87)	(6.85)
Time trend: post-1973	——	——	——	——	-0.0051	-0.0047
					(8.43)	(6.34)
Age of total capital	-0.0037	——	-0.0052	——	-0.0042	——
	(3.21)		(4.60)		(3.41)	
- Age of machinery & equipment	——	-0.0071	——	-0.0061	——	-0.0108
		(4.57)		(3.74)		(5.88)
- Age of structures	——	-0.0094	——	-0.0098	——	-0.0062
		(10.72)		(10.35)		(6.36)
Age of total capital: post-1973	——	——	——	——	0.0047	——
					(8.79)	
- Age of machinery & equipment: post-1973	——	——	——	——	——	0.0066
						(6.71)
- Age of structures: post-1973	——	——	——	——	——	0.0004
						(0.79)
Log of ratio of capital to labour	0.1343	0.1230	0.1216	0.1147	0.1427	0.1274
	(18.27)	(16.81)	(16.02)	(14.47)	(18.60)	(15.23)
Log of ratio of intermediate goods and services to labour	0.6578	0.6598	0.6572	0.6564	0.6417	0.6406
	(77.91)	(83.27)	(74.72)	(74.80)	(72.05)	(70.89)
Catch-up variable[2]	——	——	0.0059	0.0063	0.0054	0.0059
			(4.84)	(5.09)	(4.07)	(4.72)
Catch-up variable* log of capital labour ratio	——	——	0.0021	0.0020	0.0019	0.0020
			(5.80)	(5.37)	(4.76)	(5.18)
Log of R&D capital	0.0188	0.0193	0.0229	0.024 0	0.017 2	0.019 3
	(3.86)	(4.06)	(4.82)	(4.87)	(3.58)	(3.85)
Capacity utilization rates	0.0029	0.0030	0.0029	0.0030	0.0029	0.0030
	(34.34)	(34.53)	(35.08)	(34.47)	(37.35)	(35.33)
R^2	0.99	0.99	0.99	0.99	0.99	0.99
Log likelihood	1 954.15	1 948.57	1 957.75	1 946.79	1 962.36	1 952.17
ADF co-integration tests[3]	-17.71	-17.80	-17.77	-17.91	-17.83	-17.86
Sample size	660	660	660	660	660	660

1 All regressions include the dummies for 22 industries; t-statistics are in parentheses.
2 The catch-up variable is defined as the product of TFP gap and time trend.
3 The ADF tests are t-statistics from a regression of the differenced residuals on the lagged residuals, the lagged differenced residuals and industry dummies.

Therefore, we cannot reject the null hypothesis that the variables in our regressions are co-integrated. In other words, the results imply that there exists a long-term relationship between the variables of interest. However, we must be cautious in making inferences about the parameter estimates since the estimated standard errors will be biased unless the independent variables are strictly exogenous (Coe and Helpman, 1995).

The regression results are shown in Table 8. The estimated results of specification (1) show that the vintage effect, estimated by the coefficient of the age of the gross capital stock, has the expected negative sign and is significant at the 1-per-cent level. The coefficient implies that a one-year reduction in the average age of the capital stock is associated with an increase of growth in labour productivity of 0.37 per cent per year. Although this effect is not as large as what Wolff (1996) found in his paper, the vintage effect is found to be quite important for productivity growth across Canadian industries. On the basis of this coefficient and that on the capital-labour ratio, the rate of embodied technical progress in Canadian industries is 2.8 per cent per year over the 1963–92 period.[25] In contrast to Wolff (1996) who found this effect to be very large (18.9 per cent per year), our estimate is more in line with the estimate by Hulten (1992) of embodied technical progress for the United States over the 1949–83 period (3.4 per cent per year).[26]

The coefficient of the capital-labour ratio is positive and is significant at the 1-per-cent level. This effect is found to be quite strong, as the estimate suggests that a 1-per-cent increase in the capital-labour ratio leads to an increase of 0.13 per cent per year in labour productivity growth.

The time trend variable, which is a measure of the pure rate of technical progress for the manufacturing industries,[27] is estimated at 0.25 per cent per year. Not surprisingly, the rate of pure technical progress is lower for the primary and service industries than for manufacturing industries, as indicated by the negative and statistically significant coefficient of the interaction terms of the time trend with dummies identifying the primary and service industries.

Finally, the coefficient of the ratio of intermediate goods and services to labour is also significantly different from zero at the 1-per-cent level. The coefficient of the R&D capital variable has the expected positive sign and is statistically significant at the 1-per-cent level. The magnitude of the coefficient is much smaller than those found in the United States, a result consistent with typical findings; see, for example, Gera, Gu and Lee (1998). The positive and statistically significant coefficient of the capacity utilization rate reflects the pro-cyclicality of labour productivity behaviour in Canadian industries.

To test for possible differences in the rate of technical progress embodied in M&E and non-residential structures, we introduce the average age of machinery and equipment and of non-residential structures separately in specification (2). The coefficients on the age of M&E and the age of the structures are both statistically significant and have the expected negative sign. Note that the two coefficients are not significantly different from each another.

In specifications (3) and (4), we introduce the catch-up variable and an interaction term between the catch-up variable and the capital-labour ratio. The effect of all the previous independent variables remains significant and robust. The catch-up variable is found to be statistically significant at the 1-per-cent level in both specifications. Interestingly, the interaction term between the catch-up variable and the capital-labour ratio is also positive and significantly related to productivity growth. The result suggests that capital accumulation plays an important role in the catch-up process. As discussed earlier, the TFP gap in Canadian industries relative to U.S. industries presents an opportunity for the former to expand their technological frontier at a faster rate. An important role of capital accumulation is to accelerate the catch-up process through the interaction of capital formation and technological advances. Therefore, the positive coefficient on the interaction term of the catch-up variable and the capital-labour ratio also supports the embodiment hypothesis, which is a central focus of this study.

In the next specifications (5) and (6), we introduce two additional independent variables: a post-1973 time trend variable and an interaction variable between the age of the total capital stock and the post-1973 dummy. In specification (6), the latter variable is included by disaggregating the total capital stock into M&E and non-residential structures. These variables are expected to shed light on the causes of productivity slowdown across Canadian industries.

In both specifications, the coefficient on the post-1973 time trend variable is negative and statistically significant at the 1-per-cent level. This coefficient is in effect a measure of the change in the pure rate of technical progress after 1973. The results indicate that the rate of technical progress in the manufacturing industries declined from 0.65 per cent per year in the 1963–73 period to 0.14 per cent per year in the 1973–92 period. For the two primary industries, the annual rate of technical change declined from 0.02 per cent to -0.45 per cent between the two periods. The annual rate of technical change in the service industries declined from 0.18 per cent to - 0.29 per cent.

The coefficient on the interaction term involving the age of the total capital stock and the post-1973 dummy is positive and statistically significant at the 1-per-cent level. This result is interpreted to suggest that there is a decline in the rate of embodied technical progress in total capital stock: this stood at 2.9 per cent per year during 1963–73 but fell by 3.3 percentage points to -0.4 per cent per year over the 1973–92 period.

In specification (6), both interactive terms of the post-1973 dummy with the age of M&E and the age of structures are positive, indicating a slower rate of embodied technical progress in both M&E and structures after 1973.[28] The rate of embodied technical progress appears to have declined much more for M&E than for non-residential structures. Surprisingly, the rate of technical progress embodied in M&E declined sharply from 8.5 to 3.3 per cent per year after 1973. In contrast, there was only a slight decline (by 0.3 per cent per year) in the rate of technical progress embodied in non-residential structures after 1973 (from 4.9 to 4.6 per cent per year). The significant slowdown in the rate of embodied technical progress in M&E suggests that there may be a delay in reaping benefits from new types of investments such as those related to computer and communications technology. That is, in order to use these investments effectively to raise the level of productivity, organizations and workers need to change fundamentally to facilitate learning and communication.

To sum up, our major empirical results are as follows:

- Both capital-embodied technical progress (vintage effect) and catch-up possibilities for advanced technology from U.S. industries play an important role in productivity growth across Canadian industries.

- There is a complementary relationship between capital accumulation and technological advances. Capital accumulation accelerates the catch-up process as newer capital equipment that embodies advanced technology is applied in the production process.
- Canadian industries experienced a slowdown in both the rate of capital-embodied technical progress and the rate of pure technical progress after 1973. The slowdown in the rate of technical progress embodied in machinery and equipment was much more pronounced than in non-residential structures.

5. SOURCES OF PRODUCTIVITY SLOWDOWN

In this section, we identify the contribution of various factors in labour productivity growth across Canadian industries. The decomposition is based on our most comprehensive regression specification (6) in Table 8. To identify the causes of the slowdown, we decompose productivity growth separately for two periods, 1963–73 and 1973–92, for each industry. The results are presented in Tables A2 to A4 in the Appendix. To get some sense of the slowdown at the aggregate level, we take into account the size of each industry by using gross output as weights in computing productivity decomposition results.[29]

The data show that labour productivity growth across Canadian industries averaged 3.44 per cent per year over the 1963–73 period (Table 9, column 1). Of this figure, 2.31 percentage points can be attributed to the ratio of intermediate goods and services to labour, 0.34 percentage point to pure technological progress, 0.30 percentage point to the growth in the capital-labour ratio, 0.14 percentage point to capital-embodied technical progress, 0.26 percentage point to the catch-up effect, and 0.19 percentage point to R&D capital accumulation (giving an unexplained residual of -0.10 point).

However, the period from 1973 to 1992 saw a sharp turnaround as labour productivity growth slowed to 1.50 per cent per year (Table 9, column 2). Again the strongest factor was growth in the ratio of intermediate goods and services to labour, contributing to 1.23 percentage point. The contribution of capital-labour ratio growth increased from 0.30 percentage point in the 1963–73 period to 0.46 percentage point during the 1973–92 period. However, capital-embodied technical progress, which had contributed to productivity growth in the pre-1973 period, disappeared in the post-1973 period. The catch-up effect became somewhat stronger in the post-1973 period, contributing to productivity growth. A major culprit for the lower productivity growth during the post-1973 period was the rate of pure technological progress; it declined sharply from 0.34 percentage point in the pre-1973 period to -0.13 percentage point. The contribution of R&D capital accumulation remained almost unchanged.

Again in Table 9, columns 4 and 5 show the contribution of each factor to the labour productivity growth slowdown, in absolute and percentage terms respectively. Annual labour productivity growth, averaged across industries, declined by 1.94 percentage point between the 1963–73 and 1973–92 periods. The slowdown of growth in the ratio of intermediate goods and services to labour was the most important source, explaining, on average, about 56 per cent of the labour productivity slowdown. This decline may represent negative supply shocks in the 1970s, resulting from the huge increases in energy and raw material prices — a change that may have rendered part of the capital stock obsolete. It may also represent the measurement problems associated with service activities.[30]

The rate of pure technological progress explained, on average, 24 per cent of the slowdown. The vintage effect accounted for another 7 per cent of the productivity slowdown. The catch-up effect and R&D capital accumulation did not play any

Table 9
Contributions of factors to the post-1973 productivity slowdown[1]
(Average annual rate of change)

	1963–73	1973–92	Absolute slowdown	Percentage contribution to labour productivity slowdown	Percentage contribution to TFP slowdown
	(per cent)	(per cent)	(Percentage point)	(per cent)	(per cent)
Labour productivity growth	**3.44**	**1.50**	**1.94**	**100**	——
Capital-labour ratio growth	0.30	0.46	-0.16	-8.2	——
Intermediate goods and services–labour ratio growth	2.31	1.23	1.08	55.6	——
TFP growth[2]	**0.83**	**-0.19**	**1.02**	**52.6**	**100**
Normal technical progress	0.34	-0.13	0.47	24.2	46.1
Capital-embodied technical progress	0.14	0.00	0.14	7.2	13.7
Catch-up effect	0.26	0.31	-0.05	-2.6	-4.9
R&D capital accumulation	0.19	0.18	0.01	0.5	1
Residual	-0.10	-0.54	0.44	22.7	43.1

1 These calculations are based on specification (6) in Table 8. They represent weighted averages across all industries for the two periods 1963–73 and 1973–92, with weights being average gross output in these two periods.
2 TFP growth is computed as the difference between the labour productivity growth and the contributions from capital-labour growth and intermediate goods and services-labour growth.

significant role in the productivity growth decline. Growth in the capital-labour ratio increased in Canadian industries in the post-1973 period, contributing positively to productivity growth. This is in contrast to findings for the United States, where slower capital-labour ratio growth was found to account for 8 per cent of the labour productivity growth slowdown (Wolff, 1996).

Column 5 of Table 9 shows the percentage contribution of each factor for the slowdown in total factor productivity growth.[31] The rate of pure technical progress was the predominant factor, explaining, on average, 46 per cent of the TFP slowdown. Approximately 14 per cent of the TFP slowdown is attributed to the vintage effect (embodiment effect).[32] Again. the catch-up effect and R&D capital accumulation were not significant factors behind the TFP slowdown.

The contribution to productivity slowdown by each component varies across industries, as shown in Table A4 in the Appendix. In the goods-producing sector, the vintage effect was found to be the strongest in the electrical goods industry and in the wood products and furniture industry, respectively accounting for about 58 and 56 per cent of the productivity growth slowdown,. The vintage effect also contributed heavily to the slowdown in finance, insurance and real estate (FIRE) and business services, and in communications. On the other hand, the catch-up effect was found to be an important source of the slowdown mainly in service industries, such as community, social and personal services; construction; communications; and wholesale and retail trade.

6. CONCLUSIONS

Previous Canadian studies on productivity growth have been inconclusive in identifying the causes of the slowdown after 1973. The main candidates are slower growth in R&D intensity, the slowdown in infrastructure spending, a lack of technological progress in several mature industries, inter-sectoral shifts of output and labour toward services, and reduced importance of the catch-up bonus. However, none of these studies examined whether capital-embodied technical change (the vintage effect) has been a major factor in the post-1973 productivity growth slowdown across Canadian industries.

In this study, we consider the vintage effect, the catch-up effect and the capital-labour ratio to investigate the post-1973 labour productivity growth slowdown. In addition, we investigate whether complementarity exists between capital accumulation and technological advances, the idea being that capital accumulation accelerates the catch-up process as newer capital equipment embodying advanced technology is applied in the production process. We also examine the rate of embodied technical progress separately for M&E and non-residential structures capital. Last, we make use of a unique data base on the age of the capital stock in Canadian industries. This data base has not been exploited by other researchers.

Our major results can be summarized as follows:

First, we find significant and robust evidence of the vintage effect (embodied technical progress) across Canadian industries, explaining (on average) about 14 per cent of the post-1973 slowdown in TFP growth and 7 per cent of the slowdown in labour productivity growth. There are two major forces driving the vintage effect. The first is a sharp slowdown in the rate of embodied technical progress after 1973, particularly for M&E. The rate of technical progress embodied in M&E declined sharply from 8.5 per cent per year over the 1963–73 period to 3.3 per cent per year over the 1973–92 period. However, the rate of technical progress embodied in non-residential structures declined only marginally, from 4.9 to 4.6 per cent per year after 1973.

This slowdown in the rate of embodied technical progress is not surprising. Investments in M&E, particularly since 1985, have been strongly computer-related. Such investments require fundamental changes on the part of workers and organizations to reap their benefits. In a classic paper, for instance, Paul David explained how the introduction of the electric dynamo in the early 1880s (which opened the way for the commercial use of electricity) took 40 years to yield significant productivity gains: “Growth in productivity in industrial economies actually slowed down after 1890 and did not revive until the 1920s. This partly reflects the slow rate of adoption of electricity and a long time to learn how to organize production processes around electricity” (quoted in *The Economist*, September 28, 1996). Our results seem to provide support for the delay hypothesis: embodied technical progress has slowed down since 1973, suggesting that new investments take time to contribute to improved productivity performance. Another driving force behind the vintage effect is the slowdown in the trend toward newer capital stock after 1973. This slowdown was caused by the deceleration in capital accumulation in most Canadian industries after 1973.

Second, we find that the catch-up effect, though an important source of productivity growth, was not a contributing factor to the productivity slowdown after 1973. Perhaps a more significant finding is the role of capital accumulation in the catch-up process for Canadian industries. Our evidence provides support for the existence of complementarity between capital accumulation and technological progress. Through this avenue, capital accumulation accelerates the speed of catch-up by Canadian industries to their U.S. counterparts. We interpret this as an additional support for the embodiment hypothesis across Canadian industries.

Third, we find that the growth in the capital-labour ratio increased in almost all industries after 1973, contributing to an increase rather than a slowdown in labour productivity growth. This is in contrast to the findings for the United States and other major industrialized economies.

Fourth, the decline in growth of the ratio of intermediate goods and services to labour accounted for an additional 56 per cent of the labour productivity slowdown. This suggests that negative supply shocks (i.e., increases in energy and raw material prices in the 1970s) played a significant role in slowing down productivity growth in the post-1973 period. It may also reflect output measurement problems associated with the service industries.

Fifth, slower growth in R&D capital stock did not seem to contribute to the productivity slowdown.

Finally, the slowdown in the rate of pure technical progress accounted, on average, for 24 per cent of the slowdown in labour productivity growth and 46 per cent of the slowdown in total factor productivity growth. This sharp decline in the rate of pure technical progress across Canadian industries in the post-1973 period still remains a mystery and deserves further research.

NOTES

1 Studies focussing on the U.S. productivity growth slowdown have identified the following factors: the slowdown in the rate of capital accumulation, changes in the composition of the labour force, the role of energy price shocks, decreased R&D spending, employment of excess labour (relative to other industrial countries) as a result of a falling real minimum wage, and increased government regulation (Baily, 1981; Morrison, 1992; Griliches, 1994; and Baily and Gordon, 1988). Wolff (1991) suggests that the decline in investment appears to have played a major role, explaining about a fourth to a third of the slowdown in U.S. productivity growth after 1973. In addition, recent studies have emphasized measurement bias in productivity growth (see, for example, Griliches, 1994; and Baily and Gordon, 1988).

2 The effect varies across countries, from a low of 23 per cent in Japan to 69 per cent in France. For the United States, the vintage effect accounted for 55 per cent of the slowdown.

3 A previous paper by the same author (Wolff, 1991) found that embodied technical change played a significant role in the slowdown of productivity growth in the 1970s. The study covered the G-7 countries over the period from 1880 to 1979.

4 See Baily and Gordon (1988) for details on U.S. studies investigating the embodiment hypothesis. In contrast to the studies mentioned in the text, McHugh and Lane (1987*a*, *b*) found that the rate of capital-embodied technical progress may have increased during the 1970s, contrary to the overall trend of declining productivity growth during that period.

5 Although the vintage capital models formally described by Johansen (1959) and Solow (1960) have been with us for more than 30 years, there has not been any empirical analysis for Canada despite the availability of high-quality capital stock data.

6 A notable exception is Dollar and Wolff (1993).

7 Labour is allocated until the marginal product of labour is equalized across the capital of different vintages. Similarly, intermediate goods and services are allocated until the marginal products of intermediate goods and services are equalized.

8 Wolff (1991) discusses a number of avenues though which the catch-up process is associated with capital accumulation. They include the “learning by doing” effect; the positive effect of investment and output expansion on organizational design and management; the Verdoorn or Kaldor effect (investment itself may generate growth opportunities); and the stimulative effect of potential technological opportunities on investment.

9 The results based on the average values of TFP gap over the preceding two years are not significantly different.

10 Alternatively, the equation can be estimated as a growth form by taking the first difference of equation (8). However, our data on Canadian industries to be presented in the next section show that changes in capital age vary little over time and across industries. As a result, the embodied effect will be swamped by other variables and become difficult to identify statistically. In contrast, the average age of the capital stock in level form shows a substantial variation over time and across industries. Therefore, the estimating equation (8) in a level form appears to be more appropriate in analysing the embodiment hypothesis.

11 This corresponds exactly to the translog production.

12 It should be noted that when labour inputs (number of hours worked) are aggregated with the Tornqvist formula using the share of labour compensation as weights, the quality changes in labour input are adjusted to some extent.

13 See Huang (1988) for a detailed description of the methodology.

14 Wolff (1996), however, assumes a fixed service life of 39 years for non-residential structures and 14 years for machinery and equipment for the six countries analysed (France, Germany, Japan, the Netherlands, the U.K. and the United States).

15 Agricultural and industrial machinery; electrical goods; and transportation equipment.

16 There are various alternative ways to calculate labour share. It can be calculated for each country by industry over time. Another approach is to calculate the average share between countries over time (Wolff, 1991; Bernard and Jones, 1996). In this study, we allow labour share to vary across industries but restrict it to be the same across two countries.

17 These include wholesale and retail trade; restaurants and hotels; transport and storage; communications; finance, insurance and real estate (FIRE) and business services; and community, social and personal services.

18 R&D capital stocks are estimated by the equation $R_t=(1-\delta)R_{t-1}+I_{t-1}$, where δ and I_{t-1} denote the depreciation rate (assumed to be 10 per cent) and R&D expenditure respectively. The initial level of R&D is calculated by the equation $R_0=I_0/(g+\delta)$, where g is the average growth rate of R&D expenditures over the 1964–92 period. Subscript 0 refers to 1963.

19 We use gross output to account for the productive contribution of intermediate goods and services rather than their use, as in value added. See Basu and Fernald (1996).

20 It should be noted that the gross capital stock for the 22 industries in our analysis are aggregated from the PL level of aggregation (121 industries) based on a Tornqvist formula, using shares of capital income as weights.

21 There may be a measurement error in the TFP gap between Canada and the United States for the service industries. The real capital stock of the service industries in Canada, taken from the OECD International Sectoral Data Base, is adjusted for

the quality change in its computer investment component. This adjustment has not been made for the real capital stock of the service industries in the United States.

22 In our regression analysis, we pay particular attention to the following econometric issues: First, we control for unobserved industry characteristics such as industry structure, openness of industry and (perhaps more important) the quality of industry labour force by introducing industry dummies. Second, we allow for possible differences in the rate of normal technical progress between industries by introducing interaction terms between industry dummy variables and the time trend. Third, we allow for the correlation of error terms across industries since the industries are subject to similar external and internal macro-economic fluctuations. Fourth, we introduce a first-order autoregression AR(1) process in error terms since the data reveal a high degree of autocorrelation within industries. Finally, we take into account heteroscedasticity across industries. The hypotheses that there are no autocorrelation, no cross-sectional heteroscedasticity and no cross-sectional correlation are all rejected using a likelihood test. See Kmenta (1986) for a detailed discussion.

23 The pooled unit root tests by Levin and Lin (1992) assume independence of error terms across cross-sectional units. O'Connell (1996) has shown that allowing for cross-correlation, as in our regression analysis, increases the nominal size of such tests.

24 Levin's and Lin's pooled unit root tests are used to test the non-stationarity of the residuals for co-integration.

25 The rate of embodied technical progress is calculated as $-a_2/a_3$, where a_2 is the coefficient on the age of the capital stock and a_3 is the coefficient of the capital-labour ratio. See equation (7) for the derivation.

26 For the United States, Intriligator (1965) estimated a rate of embodied technical progress at 4.0 per cent per year over the period from 1958 to 1983. However, Wolff (1996) has obtained much higher estimates of embodied technical progress for the G-6 countries (excluding Canada), ranging from 2.63 to 7.18 per cent per year.

27 The rate of pure technical progress was not statistically different between manufacturing industries. Therefore, the interaction terms were introduced only to allow for differences between primary, manufacturing and service industries.

28 The coefficient on the interactive term of the post-1973 dummy with the age of structures is not statistically significant. However, the sum of the coefficients on the age of structures and its interactive term with the post-1973 dummy is statistically significant, indicating that the estimate of the post-1973 rate of embodied technical progress in structures is statistically significant.

29 However, the results using simple averages are not different.

30 We are thankful to Richard Harris for suggesting this point.

31 TFP growth in Table 8 is equal to labour productivity growth minus the contributions of growth in the capital-labour ratio and in the ratio of intermediate goods and services to labour.

32 In contrast, Wolff (1996) finds a larger vintage effect, explaining about 40 per cent of the total factor productivity slowdown based on a sample of six countries. Part of this larger estimated effect may be attributed to his use of value added instead of gross output, as in this paper.

APPENDIX

Table A1
Pooled unit root tests

(Annual data for 22 industries over the 1963–92 period, 660 observations)

Variables	**ADF test statistics**[1]
Log of labour productivity	-4.29
Age of total capital stock	-7.33
Age of machinery and equipment	-9.54
Age of non-residential structures	-8.89
Log of ratio of capital to labour	-6.58
Log of ratio of intermediate goods and services to labour	-5.00
Catch-up variable	-5.98
Catch-up variable* log of capital-labour ratio	-5.81
Log of R&D capital stock	-5.28
Capacity utilization rates	-15.73

1 The Augmented Dickey Fuller tests are t-statistics from a regression of the first difference of a variable on the lagged variable, the lagged first difference of the variable, time trend and industry dummies.

2 The critical values for the unit root test are -7.07 at the 5-per-cent significance level and -6.78 at the 10-per-cent significance level (Levin and Lin 1992).

Table A2
Contribution to labour productivity growth by each component, 1963–73
(percentage points)[1]

Industry (ISIC Rev. 2)	lpgrt	Time trend	Age of M&E	Age of struct	klgrt	xlgrt	Catch up	Catch up*kl	rdgrt	Resid
1. Agriculture, forestry & fishery	4.96	0.02	0.10	0.01	0.70	4.77	-0.02	-0.03	0.68	-1.28
2. Mining & quarrying	5.37	0.02	0.12	-0.07	0.69	3.50	0.05	0.09	0.15	0.82
3. Food, beverages & tobacco	3.23	0.60	0.08	0.04	0.42	1.86	0.01	0.01	0.13	0.10
4. Textiles, apparel & leather	4.46	0.60	0.27	0.25	0.14	3.08	0.00	0.00	0.03	0.06
5. Wood products & furniture	3.29	0.60	0.23	0.27	0.20	2.38	0.21	0.21	0.18	-0.99
6. Paper, paper products & printing	3.10	0.60	0.01	0.35	0.38	2.33	0.21	0.29	0.06	-1.12
7. Chemicals	4.26	0.60	0.03	0.06	0.34	2.58	0.27	0.40	0.11	-0.12
8. Non-metallic mineral products	3.88	0.60	-0.04	0.13	0.53	2.11	0.06	0.08	0.15	0.26
9. Basic metal industries	2.88	0.60	-0.02	-0.10	0.37	1.87	0.20	0.30	0.08	-0.41
10. Metal products	3.44	0.60	0.22	-0.07	0.21	2.09	0.08	0.08	0.23	0.01
11. Agricultural & industrial mach.	3.95	0.60	0.13	0.13	0.31	3.41	0.19	0.16	0.17	-1.15
12. Electrical goods	4.09	0.60	0.17	-0.07	0.24	2.37	-0.11	-0.09	0.16	0.82
13. Transport. equipment	5.95	0.60	0.25	0.18	0.11	3.36	0.12	0.13	0.10	1.11
14. Other manufacturing industries	4.01	0.60	0.01	0.10	0.37	2.59	0.17	0.14	0.16	-0.12
15. Electricity, gas & water	5.16	0.18	0.17	-0.03	0.30	2.21	0.31	0.67	0.43	0.94
16. Construction	2.48	0.18	0.06	-0.13	0.13	2.23	0.08	0.05	0.19	-0.31
17. Wholesale and retail trade	2.17	0.18	0.09	-0.03	-0.08	0.71	0.12	0.09	0.21	0.88
18. Restaurants and hotels	1.26	0.18	0.08	0.08	0.23	0.70	-0.21	-0.18	0.21	0.17
19. Transport & storage	5.47	0.18	-0.04	0.22	0.41	3.93	0.29	0.43	0.15	-0.09
20. Communications	6.03	0.18	-0.02	0.20	0.28	1.95	0.30	0.50	0.30	2.34
21. FIRE & business services	1.70	0.18	0.07	0.27	0.41	1.84	0.16	0.19	0.21	-1.64
22. Community, social & personal services	1.03	0.18	-0.00	0.04	0.36	0.43	0.30	0.36	0.21	-0.85
Average[2]	3.44	0.34	0.08	0.06	0.30	2.31	0.11	0.15	0.19	-0.10

1 lpgrt = annual rate of labour productivity growth.
Age of M&E = annualized change in the average age of machinery and equipment.
Age of struct = annualized change in the average age of non-residential structures.
klgrt = annual rate of growth in the ratio of gross capital to labour.
xlgrt = annual rate of growth in the ratio of intermediate goods to labour.
Catch up = catch-up variable defined as TFP gap times time trend.
Catch up*kl = interactive term between the catch-up variable and the log of capital-labour ratio.
rdgrt = annual rate of growth of the R&D capital stock.
Resid = unexplained portion.

2 Weighted average with weights being the mean values of gross output for the period 1963–73.

Table A3
Contribution to labour productivity growth by each component: 1973–92
(percentage points)[1]

Industry (ISIC Rev. 2)	lpgrt	Time trend	Age of M&E	Age of struct	klgrt	xlgrt	Catch up	Catch up*kl	rdgrt	Resid
1. Agriculture, forestry & fishery	2.85	-0.45	-0.00	-0.01	0.10	1.90	0.07	0.09	0.31	0.84
2. Mining & quarrying	0.91	-0.45	-0.01	-0.03	0.60	1.87	0.24	0.51	0.07	-1.90
3. Food, beverages & tobacco	1.58	0.13	0.04	-0.08	0.40	1.20	0.14	0.19	0.04	-0.47
4. Textiles, apparel & leather	2.40	0.13	0.04	-0.07	0.42	1.40	0.13	0.13	0.05	0.18
5. Wood products & furniture	2.51	0.13	0.00	-0.04	0.51	1.72	0.12	0.18	0.16	-0.27
6. Paper, paper products & printing	1.22	0.13	0.03	-0.01	0.53	1.22	0.20	0.35	0.01	-1.24
7. Chemicals	0.75	0.13	0.02	-0.08	0.51	0.12	0.23	0.44	0.08	-0.69
8. Non-metallic mineral products	0.68	0.13	0.01	-0.09	0.51	0.79	0.07	0.12	0.04	-0.92
9. Basic metal industries	2.33	0.13	0.00	-0.02	0.65	1.66	0.04	0.11	0.05	-0.29
10. Metal products	0.93	0.13	0.01	0.00	0.26	0.69	0.12	0.14	0.08	-0.51
11. Agricultural & industrial machinery	3.41	0.13	0.04	-0.05	0.60	2.50	0.11	0.16	0.07	-0.15
12. Electrical goods	3.83	0.13	0.03	-0.08	0.69	2.57	0.23	0.24	0.12	-0.11
13. Transport. equipment	1.99	0.13	0.05	0.02	0.62	1.38	0.06	0.12	0.10	-0.49
14. Other manufacturing industries	0.46	0.13	0.02	-0.05	0.51	0.12	0.29	0.33	0.15	-1.04
15. Electricity, gas & water	1.41	-0.29	0.00	-0.11	0.33	2.35	0.32	0.77	0.20	-2.15
16. Construction	1.23	-0.29	0.00	0.07	0.54	0.60	-0.15	-0.11	0.21	0.35
17. Wholesale and retail trade	1.29	-0.29	0.04	-0.02	0.14	0.93	0.02	0.02	0.33	0.12
18. Restaurants and hotels	-0.55	-0.29	0.01	0.06	0.58	0.23	0.32	0.32	0.33	-2.12
19. Transport & storage	1.89	-0.29	0.07	0.02	0.31	1.44	0.16	0.29	0.09	-0.20
20. Communications	5.69	-0.29	0.04	0.01	0.44	2.74	0.22	0.47	0.25	1.81
21. FIRE & business services	1.21	-0.29	0.01	-0.01	0.75	1.77	0.12	0.22	0.33	-1.70
22. Community, social & personal services	0.52	-0.29	0.04	-0.21	0.43	0.95	0.06	0.13	0.33	-0.93
Average[2]	1.50	-0.14	0.02	-0.02	0.46	1.23	0.11	0.20	0.18	-0.54

1 See note 1, Table A2.
2 Weighted average with weights being the mean values of gross output for the period 1973–92.

Table A4
Contribution to the post-1973 productivity slowdown by each component (percentage points)[1]

Industry (ISIC Rev. 2)	lpgrt[2]	Time trend	Age of M&E	Age of struct	klgrt	xlgrt	Catch up	Catch up*kl	rdgrt	Resid
1. Agriculture, forestry & fishery	2.11	0.47	0.11	0.03	0.60	2.87	-0.10	-0.12	0.37	-2.12
2. Mining & quarrying	4.46	0.47	0.12	-0.04	0.09	1.63	-0.19	-0.43	0.09	2.72
3. Food, beverages & tobacco	1.64	0.47	0.03	0.12	0.02	0.65	-0.14	-0.18	0.09	0.57
4. Textiles, apparel & leather	2.05	0.47	0.24	0.33	-0.28	1.69	-0.13	-0.13	-0.02	-0.11
5. Wood products & furniture	0.78	0.47	0.23	0.31	-0.31	0.66	0.10	0.03	0.02	-0.73
6. Paper, paper products & printing	1.88	0.47	-0.02	0.36	-0.15	1.10	0.01	-0.07	0.04	0.12
7. Chemicals	3.51	0.47	0.02	0.15	-0.17	2.45	0.04	-0.04	0.03	0.57
8. Non-metallic mineral products	3.20	0.47	-0.05	0.22	0.03	1.32	-0.01	-0.04	0.10	1.17
9. Basic metal industries	0.56	0.47	-0.02	-0.08	-0.28	0.21	0.16	0.19	0.03	-0.11
10. Metal products	2.52	0.47	0.21	-0.07	-0.05	1.40	-0.04	-0.06	0.15	0.52
11. Agricultural & industrial machinery	0.54	0.47	0.09	0.18	-0.29	0.91	0.08	-0.00	0.09	-0.99
12. Electrical goods	0.26	0.47	0.14	0.01	-0.45	-0.20	-0.34	-0.33	0.03	0.93
13. Transport. equipment	3.96	0.47	0.20	0.16	-0.51	1.97	0.06	0.01	-0.00	1.60
14. Other manufacturing industries	3.56	0.47	-0.01	0.15	-0.14	2.46	-0.11	-0.19	0.00	0.92
15. Electricity, gas & water	3.75	0.47	0.16	0.08	-0.03	-0.15	-0.01	-0.10	0.23	3.09
16. Construction	1.25	0.47	0.06	-0.20	-0.41	1.63	0.23	0.16	-0.02	-0.67
17. Wholesale and retail trade	0.88	0.47	0.05	-0.02	-0.22	-0.22	0.10	0.07	-0.11	0.76
18. Restaurants and hotels	1.81	0.47	0.06	0.02	-0.36	0.47	-0.54	-0.50	-0.11	2.29
19. Transport & storage	3.58	0.47	-0.11	0.19	0.09	2.48	0.13	0.15	0.06	0.11
20. Communications	0.35	0.47	-0.05	0.19	-0.16	-0.79	0.07	0.03	0.05	0.53
21. FIRE & business services	0.50	0.47	0.05	0.28	-0.34	0.07	0.04	-0.03	-0.11	0.06
22. Community, social & personal services	0.51	0.47	-0.04	0.25	-0.07	-0.52	0.23	0.23	-0.11	0.07
Average	1.94	0.47	0.06	0.08	-0.17	1.08	0.01	-0.05	0.01	0.44

1 See note 1, Table A2.
2 The slowdown in the annual rate of growth of labour productivity between the 1963–73 period and 1973–92 period (percentage points).

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E-Mail: fumerton.cheryl@ic.gc.ca