

ACCOUNTING FOR CANADA'S ECONOMIC GROWTH

STEPHEN KOSEMPPEL AND KENNETH CARLAW

University of Guelph and the University of Canterbury

A dynamic stochastic general equilibrium model is constructed and calibrated to the Canadian economy. Technology disturbances from the Canadian economy are filtered through the model and used to generate artificial time series. Output growth in the model is then decomposed into the share weighted growth rates of the factor inputs and productivity. The model is then used to identify the endogenous responses of the factor inputs to the technology disturbances. The results suggest that much of the slowdown observed in Canadian output growth since 1974 can be explained by fluctuations in the rates of investment-specific and residual-neutral technological change.

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JEL classification: E30, O43, O47

1. INTRODUCTION

Real GDP per capita in Canada grew by a factor of 1.9 from \$15,751 in 1961 to \$29,695 in 1996, all measured in 1992 dollars. This increase corresponds to an average growth rate of 1.9 percent per year. However, the average annual growth rate over the entire 1961-96 period may provide a misleading estimate of Canada's more recent economic performance, because Canada experienced relatively rapid growth over the earlier years in the sample period and slow growth over the later years. For example, GDP per capita grew at an average annual rate of 3.3 percent during the 1961-73 period, but then slowed to 1.1 percent during the 1974-96 period. The purpose of this paper is to identify the sources of growth in Canadian real GDP per capita during the 1961-96 period and to explain differences in growth rates between the two sub-periods.

Growth accounting studies involve the decomposition of output growth into the share weighted growth rates of the labor and capital inputs and the rate of technological change. Typically, the production function residual is used to provide a measure of the rate of technological change. However, the residual alone does not provide an accurate measure of the contribution of technology to output growth. This is because it does not account for the induced expansion of capital which is, at least in part, an endogenous

response to technological change. In order to make inferences about the contribution of various technologies to the rate of capital accumulation, a dynamic stochastic general equilibrium model of the economy is employed. The results show that much of the slowdown observed in Canada's GDP growth since 1974 can be explained by fluctuations in the rates of technological change.

Technological advancements are separated into two categories: residual-neutral technological change (RNT) and investment-specific technological change (IST). RNT captures changes in productivity associated with the organization of capital and labor. It also captures improvements in the quality of labor, to the extent that those improvements are not accounted for in the measure of the labor input. IST accounts for improvements in the quality of capital, as it captures technological advancements embodied in new machinery and equipment. Since IST measures improvements to product quality, it captures the fact that more effective units of output are being produced per unit of capital and labor employed. The decomposition of technological change into RNT and IST is necessary partly because the growth rate of Canada's GDP is sensitive to the type of technology developed, and partly because the two forms of technology differ in their time series behavior.

A recent IMF report on Canada revealed that the average annual rate of IST was higher, and the rate of RNT lower, after the rate of GDP growth slowed, 1974 (see Dunaway et al., 2000). Table 1 summarizes the measures of IST and RNT relative to the rate of GDP growth over selected periods. The average annual rate of IST increased from 1.29 percent over the 1961-73 period to 5.12 percent over the 1974-96 period. In comparison, the average annual rate of RNT declined from 1.80 percent over the 1961-73 period to -0.07 percent over the 1974-96 period.¹ These observations lead the reader to correctly conclude that the increase in the rate of IST was not sufficiently large to compensate for the reduction in the rate of RNT, and therefore the rate of GDP growth slowed. However, the data displayed below and in the IMF report do not provide answers to a number of important questions. First, through what channels do RNT and IST affect the rate of GDP growth? Second, how sensitive is the rate of GDP growth to changes in the rates of technological change? The current paper provides answers to these questions, and attempts to improve our understanding of the various sources of growth, by quantifying the individual contributions of IST and RNT to the growth rate of real GDP per capita in Canada for selected periods.

¹ On the surface it appears that we have experienced negative technology growth, something that is implausible in a maximizing framework. Our index of input neutral efficiency improvement has changed negatively, but this could reflect a trade off between new embodied technology today and input neutral efficiency growth in the future.

Table 1. Average Annual Growth Rates: Real GDP Per Capita and Technology

	1961-73	1974-96	1961-96
Real GDP Per Capita	3.34%	1.09%	1.86%
Investment-Specific Technology ¹⁾	1.29%	5.12%	3.81%
Residual-Neutral Technology	1.80%	-0.07%	0.57%

Notes: ¹⁾ The time path of IST was tracked using movements in the relative price of equipment. Between 1961 and 1996 the price of new equipment relative to the price of consumer non-durables and services declined by approximately 4.0 percent per year, while the rate of investment in equipment rose by 4.0 percent per year. This negative co-movement has been interpreted in the literature as evidence of IST (see Greenwood *et al.* (2000, 1997), Dunaway *et al.* (2000)).

This analysis adds to the existing literature on IST, RNT and their contribution to growth (e.g., Carlaw and Kosempel (2000), Greenwood, Hercowitz and Krusell (2000, 1997)). Our earlier study identified the channels through which RNT and IST affect total factor productivity (TFP) growth, whereas the current study attempts the somewhat more difficult task of isolating the contribution of the technologies to the rate of GDP growth. The task is more difficult because GDP growth can occur if new technologies improve the productivity of existing resources, that is if they affect TFP, or if they lead to increases in the quantity of resources available for production.

Greenwood, Hercowitz and Krusell (1997) have studied the effects of RNT and IST on U.S. labor productivity growth. In their study technological change was restricted to occur at constant rates. In other words, their study focused only on the U.S. economy's long run growth path. However, in the Canadian economy the rates of technological change and the growth rate of real GDP per capita were found to depend on the period studied (see Table 1). As such, in the current paper the rates of technological change are allowed to fluctuate. The current study is also the first to be based on Canadian rather than U.S. rates of technological change and growth.

Greenwood, Hercowitz and Krusell (2000) have also studied the effects that investment-specific technology shocks have on the business cycle. In their model, a positive investment-specific technology shock lowers the price of new equipment relative to the price of nondurable consumption goods and services, and therefore stimulates investment and increases output. Thus, the quality of new equipment and output are positively related in their model. However, we have observed a negative correlation between the detrended quality of new equipment goods and GDP in the Canadian economy during the 1961-96 period. In Canada advances in investment-specific technology appear to be associated with economic slowdowns. In order to explain this puzzle, we build on the Greenwood *et al.* model.

In order to explain the negative correlation observed between quality and output in the Canadian data, it is necessary to incorporate residual-neutral technology shocks into the Greenwood *et al.* model and to account for the specific timing of the technology disturbances. Greenwood *et al.* do not consider the timing of the technology disturbances

to be an important factor in their model. The common procedure applied in the literature, and the procedure used by Greenwood *et al.*, is to obtain technology disturbances from a random number generator on a computer. However, this procedure cannot guarantee that IST will grow faster, and RNT slower, after 1974. In order to account for the timing of technology shocks, the actual technology disturbances from the Canadian economy will be filtered through the model and used to generate fluctuations in the model's simulated time series. In our model, IST is high when RNT is low, as it is in the data. Furthermore, since RNT was low during the post-1974 period, output was low. This is true despite the fact that IST was high and had a positive effect on output during the later period. As a result, in the model economy the quality of new capital is high when output is low, as it is in the data.

The paper is organized as follows: The model to be studied is constructed in Section 2. The results are presented and discussed in Section 3. Concluding remarks are provided in Section 4.

2. THE MODEL

The model is a version of the real business cycle (RBC) model constructed by Greenwood *et al.* (2000) which allows for new equipment to become increasingly more efficient with the passage of time.

2.1. Households

The representative household maximizes the expected value of a discounted stream of utility given by

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, l_t), 0 < \beta < 1, \quad (1)$$

where c_t and l_t denote the date t levels of consumption and leisure. The household's time endowment is normalized to one, and therefore $l_t + n_t = 1$, where n_t denotes the fraction of time devoted to work. The momentary utility function has the following form:

$$U(c_t, l_t) = \begin{cases} \frac{(c_t^\omega l_t^{1-\omega})^{1-\gamma} - 1}{1-\gamma} & \text{if } 0 < \gamma < 1 \text{ or } \gamma > 1, \\ \omega \ln c_t + (1-\omega) \ln l_t & \text{if } \gamma = 1. \end{cases} \quad (2)$$

The household budget constraint is given by,

$$c_t + i_{s,t} + p_t q_t i_{e,t} \leq (1 - \tau_n) w_t n_t + (1 - \tau_k) (r_{s,t} s_t + r_{e,t} e_t) + \tau_t - a_{s,t} - p_t a_{e,t}. \quad (3)$$

This states that the household's expenditures on consumption and investment are bounded by after tax total income less adjustment costs. The real wage rate is denoted by w_t , the real rental rate of structures by $r_{s,t}$ and the real rental rate of equipment by $r_{e,t}$. Labor income is taxed at a rate of τ_n , and capital income at a rate of τ_k . The household receives a lump-sum transfer of τ_t from government. The capital stock comprises structures, s_t , and equipment, e_t . Investment expenditures for structures are $i_{s,t}$ and $p_t q_t i_{e,t}$ for equipment, where p_t measures the purchase price of new equipment relative to the price of the consumption good and q_t indicates the quality (or relative efficiency) of the newest vintage of equipment. Installing new capital may require adjustment costs - $a_{s,t}$ for structures and $p_t a_{e,t}$ for equipment. The adjustment cost functions are assumed to have the following form,²

$$a_{x,t} = \frac{\theta_x (x_{t+1} - \psi_x x_t)^2}{x_t}, \quad x \in \{s, e\}. \quad (4)$$

All variables in the household's budget constraint are measured in consumption units. Thus, each unit of investment in structures costs one unit of consumption, and each unit of equipment costs p_t units of consumption. In the data, the relative price series displays a downward trend - indicating that investment in equipment is becoming relatively less expensive as time passes. Efficiency gains also lead to cost savings for investors. For this reason, the reciprocal of the relative price provides a measure of the efficiency, or the quality (q_t), of the newest vintage of equipment.³

The household's capital stocks evolve according to:

$$i_{s,t} = s_{t+1} - (1 - \delta_s) s_t, \quad \text{and} \quad (5)$$

² This configuration of adjustment costs is convenient partly because it allows for balanced growth, and partly because the adjustment cost parameters can be set to control the volatility of the investment series. With quadratic adjustment costs, the cost of increasing the capital stock by a fixed amount increases with the speed of the desired adjustment. Adjustment cost functions with the same parameterization have been used in other studies (see Greenwood *et al.* (2000), or Mendoza (1991)).

³ In this analysis all movements in the relative price are perceived as IST. We feel that IST is the most likely explanation for the downward trend observed in this time series. However, it is not inconceivable that other economic forces have some bearing on relative price movements. For example, since Canada is a net importer of capital goods and net exporter of raw materials, movements in the terms of trade may also affect the relative price.

$$q_t i_{e,t} = e_{t+1} - (1 - \delta_e) e_t. \quad (6)$$

Here δ_s and δ_e denote the rates of depreciation of structures and equipment, respectively.

2.2. Firms

Firms are competitive and seek to maximize profits,

$$\max_{\{N_t, S_t, E_t\}} \pi_t = F(N_t, S_t, E_t; A_t) - w_t N_t - r_{s,t} S_t - r_{e,t} E_t. \quad (7)$$

The production technology is Cobb-Douglas,

$$F(N_t, S_t, E_t; A_t) = A_t N_t^{\alpha_n} S_t^{\alpha_s} E_t^{\alpha_e}, \text{ with } \alpha_n + \alpha_s + \alpha_e = 1, \quad (8)$$

where A_t denotes the state of residual-neutral technology. Since residual-neutral technological advancements improve the economy's ability to produce all types of goods, they do not alter relative prices. The output produced via (8) is sold to households, who then allocate it for consumption or investment purposes.

2.3. Technological Processes

The technologies follow the laws of motion given by:

$$A_t = z_{A,t} g_A^t, \text{ where} \quad (9)$$

$$\ln z_{A,t} = \rho_A \ln z_{A,t-1} + \varepsilon_t, \text{ with } 0 < \rho_A < 1, \varepsilon \sim iid N(0, \sigma_\varepsilon^2); \quad (10)$$

$$q_t = z_{q,t} g_q^t, \text{ where} \quad (11)$$

$$\ln z_{q,t} = \rho_q \ln z_{q,t-1} + v_t, \text{ with } 0 < \rho_q < 1, v \sim iid N(0, \sigma_v^2). \quad (12)$$

Here g_A and g_q denote the gross long run rates of RNT and IST, respectively. The variables $z_{A,t}$ and $z_{q,t}$ are technology shocks - $z_{A,t}$ captures the deviations of the residual-neutral technology series from its deterministic trend and $z_{q,t}$ deviations of the investment-specific technology series from its deterministic trend.

2.4. Government

The government taxes labor and capital income and then rebates the proceeds to households subject to the following budget constraint:

$$\tau_t = \tau_n w_t n_t + \tau_k (r_{s,t} s_t + r_{e,t} e_t). \quad (13)$$

2.5. Competitive Equilibrium

A competitive equilibrium consist of an allocation $\{c_t, i_{s,t}, q_t i_{e,t}, n_t, s_t, e_t\}_{t=0}^{\infty}$ for the typical household, an allocation $\{N_t, S_t, E_t\}_{t=0}^{\infty}$ for the typical firm and a set of prices $\{p_t, w_t, r_{s,t}, r_{e,t}\}_{t=0}^{\infty}$, such that:

1. The household's allocation solves the household's problem of maximizing (1) subject to (2)-(6), taking prices as given;
2. The firm's allocation solves the firm's problem of maximizing (7), taking prices as given;
3. The government's budget constraint (13) is satisfied; and
4. All markets clear: $n_t = N_t, s_t = S_t, e_t = E_t,$

$$c_t + i_{s,t} + i_{e,t} + a_{s,t} + \frac{a_{e,t}}{q_t} = F(N_t, S_t, E_t; A_t). \quad (14)$$

Combined, the accumulation equation for equipment (6) and the resource constraint (14) indicate that a household can acquire $q_i e_t$ units of new equipment at a cost of i_e units of current consumption. Despite its appearance, the quality component embodied in new equipment is not free. Households pay a price for each efficiency unit of equipment ($q_i e_t$) that they purchase. However, when output is measured in units of the consumption good, quality improvements lower the unit price ($p = 1/q$) of new equipment. A lower unit price offsets the charge for higher quality. As a result, quality improvements do not appear in the total cost of an investment in equipment.

When all types expenditure and sources of income have been divided by the price of the consumption good, so that each item has a constant unit of measurement, the measure of output is as shown by Equation (14). In the data, however, investment expenditures are not measured in terms of forgone consumption. Instead a separate deflator is applied to each category of expenditure, so that each item is measured in

constant dollars, but not necessarily in a common unit. In the data, nominal output ($p_y y$) is given by

$$p_{y,t} y_t \equiv p_{c,t} c_t + p_{i_s,t} i_{s,t} + p_{i_e,t} q_t i_{e,t} + p_{a_s,t} a_{s,t} + p_{a_e,t} a_{e,t}, \quad (15)$$

and real output (y) by

$$y_t \equiv c_t + i_{s,t} + q_t i_{e,t} + a_{s,t} + a_{e,t}. \quad (16)$$

Here p_x denotes the implicit price deflator for item $x \in (y, c, i_s, i_e)$. Notice the estimate of output obtained from the data (16) does not coincide with the estimate obtained via (14). Quality improvements add to total output (y), but they do not add to total expenditures (F).

2.6. Balanced Growth

This section describes the balanced growth path of the model economy. The growth rates of the variables along the balanced growth path are determined as follows. First, time devoted to work is constant in balanced growth. Second, from the resource constraint (14) and the accumulation equation for structures (5) it follows that $F(\cdot)$, c , i_s , i_e , a_s , a_e/q , and s all have to grow in the long run at the same gross rate - say g . This restriction combined with the accumulation equation for equipment (6) implies that $q i_e$, e and a_e all grow in the long run at a gross rate of $g_e = g_q \times g$. Next, the production function implies that $g = g_A g^{\alpha_n} g_e^{\alpha_e}$. Finally, by combining these restrictions it can be shown that:

$$g = g_A^{\frac{1}{\alpha_n}} \times g_q^{\frac{\alpha_e}{\alpha_n}}, \quad \text{and} \quad (17)$$

$$g_e = g_A^{\frac{1}{\alpha_n}} \times g_q^{\frac{\alpha_n + \alpha_e}{\alpha_n}}. \quad (18)$$

The model and the Canadian economy share many common average growth properties. For example, hours worked per capita does not grow in the steady state, the real interest rate (or the rate of return on a capital investment) follows a horizontal trend, the rate of investment in equipment ($q i_e / y$) displays a positive trend, and output (y or GDP) does not have a balanced growth path - its average growth rate converges to g_e .

2.7. Calibration

Before the decision rules can be computed and an artificial time series can be generated, it is necessary to assign values to the model's parameters. Parameter values are set using evidence from the relevant empirical literature, to achieve certain long run averages observed in the Canadian economy and to satisfy the restrictions imposed by the structure of the model.

Technology Parameters. Values for the parameters in the technological processes are set so that the time series properties of the technologies in the model and the data are the same. The long run rate of IST ($g_q - 1$) is set to 3.81 percent, and matches the average annual rate of decline in the relative price of equipment. The long run rate of RNT ($g_A - 1$) is set to 0.64 percent. For this value, the long run growth rate of total expenditures ($g - 1$) in the model is 1.72 percent (as calculated from Equation (17)), which matches the average annual growth rate of total expenditures in the Canadian economy. The long run growth rate of the equipment stock ($g_e - 1$) is equal to 5.60 percent, and was set to satisfy (18).

The time series for both technologies were detrended via linear regression lines. Auxiliary regressions were then performed to obtain estimates of the parameters in Equations (10) and (12). The results of these regressions suggest the following values: $\rho_A = 0.8834$ (14.91), $\sigma_\varepsilon = 0.0174$, $\rho_q = 0.8766$ (16.31), and $\sigma_v = 0.0387$. Values in parenthesis are t -statistics. The autocorrelation coefficients in both processes are statistically significant at a 1 percent level.

Labor's share parameter (α_n) is set to 0.7082, and matches the ratio of labor income to total income in Canada. Capital's share parameters are set so that in the steady state the purchases of structures accounts for 5.90 percent of total expenditures and the purchases of equipment 7.49 percent: $\frac{i_s}{F(\cdot)} = 0.0590$ and $\frac{i_e}{F(\cdot)} = 0.0749$. These values were obtained from the data, and imply $a_s = 0.1392$ and $a_e = 0.1525$.

Depreciation Rates. The rates of capital depreciation are consistent with common practice in the relevant literature (see Greenwood *et al.* (2000, 1997), or Dunaway *et al.* (2000), $\delta_s = 0.056$ and $\delta_e = 0.124$).

Tax Rates. The tax rate on labor income (τ_n) is set to 40 percent. This is the value listed in the IMF report on Canada (see Dunaway *et al.* (2000)). The tax rate on capital income (τ_k) is set to 44.43 percent, so that in the steady state the after tax rate of return to capital is 4 percent per year.

Preference Parameters. A survey of the micro evidence on the coefficient of relative risk aversion (γ) was conducted by Mehra and Prescott (1985). Their survey suggests that γ is between 1 and 2. As a compromise a value of 1.5 was selected. The share parameter in the utility (ω) function is set to 0.5047, so that households spend on

average 1/3 of their time at work. This value is consistent with evidence on household time use. The discount factor (β) is equal to 0.9823, and was set to satisfy the Capital Accumulation Euler equations.

Adjustment Cost Parameters. Unfortunately, long run evidence does not provide information that will help in determining appropriate values for the parameters in the adjustment cost functions. Instead, their values are set following the procedure outline by Greenwood *et al.* (2000). For a justification of this procedure, we refer readers to their paper. First, ψ_s is set equal to g and ψ_e to g_e , so that no adjustments costs are incurred along the balanced growth path. Second, the symmetry condition $\theta_s = g_q^2 \theta_e \equiv \theta$ is imposed, after which only one adjustment cost parameter remains to be determined, θ . Adjustment costs have been included to moderate the variability of capital accumulation. By setting θ to 0.733, equipment investment in the model (qi_e) has the same standard deviation as real per capita non-residential fixed investment in machinery and equipment in Canada.

3. THE RESULTS

The residual-neutral and investment-specific technology series were filtered through the model, and artificial time series were generated for the other variables in the model. Various statistics that summarize the time series behavior of the Canadian and artificial economy are displayed in the tables and figures below.

3.1. Business Cycles

Annual business cycle statistics for Canada are displayed in Table 2 and for the model in Table 3. The model's ability to mimic key aspects of Canadian business cycle behavior is important, otherwise it will not do a good job explaining fluctuations in the rate of GDP growth between periods. A comparison of Tables 2 and 3 reveals that the model shares many of the same strengths and weaknesses with other specifications of the RBC model. For a description and evaluation of other RBC models readers are referred to Kydland (1995), Christiano and Eichenbaum (1992) or Hansen and Wright (1992).

The model's strengths:

1. Investment is three times more volatile than output and consumption is less volatile than output.
2. Investment, consumption, and hours worked are all procyclical as they are in the data.
3. There is a positive relationship between output and the relative price in both the

model and the data. The strength of this relationship is also similar.

The model's weaknesses:

1. In the artificial economy output fluctuates less than in the Canadian economy, suggesting that much, but not all, of the variation in output can be explained by technology disturbances.
2. Some of the labor market predictions are counterfactual. For example, in the artificial economy hours worked is considerably less volatile than it is in the data and labor productivity is too highly correlated with output.

Judged on the dimension of the composition of output and its co-movements, the match between the model and the data is pretty good but certainly not perfect. The model does display a business cycle.

Table 2. Annual Canadian Business Cycle Statistics, 1961-96¹⁾

Variable	Standard Deviation	Correlation with Output
Output	1.70	1.00
Consumption	1.21	0.89
Investment	5.32	0.49
Relative Price	2.49	0.41
Hours Worked	1.61	0.87
Labor Productivity	0.85	0.34

Notes: ¹⁾ Before statistics were reported all series were converted to 1992 dollars, deflated by the 16+ population, logged and then detrended via the Hodrick-Prescott (HP) filter. The smoothing parameter in the HP filter was set to 10. Baxter and King (1995) suggest that a value of 10 is appropriate for annual data. The data is described in detail in the appendix.

Table 3. Artificial Economy Business Cycle Statistics¹⁾

Variable	Standard Deviation	Correlation with Output
Output (y)	1.21	1.00
Consumption	1.10	0.97
Investment	3.44	0.79
Relative Price	2.49	0.49
Hours Worked	0.18	0.64
Labor Productivity	1.10	0.99

Note: ¹⁾ Each simulated time series was logged and detrended using the same procedures applied to the Canadian sample.

The dynamic behavior of the model can be described by the impulse responses that it generates. For example, a positive residual-neutral technology shock increases the marginal product of each input. In turn, this induces a greater than normal demand for each input. Furthermore, this increase in the demand raises the real wage rate and the real rental rates of capital, and therefore provides an additional incentive to work and to undertake capital investments. Output also responds positively to this shock. The positive response of output is partially a result of the fact that productivity is higher for a given amount of labor and capital, and partially due to the increase in employment.

In comparison, a positive investment-specific technology shock lowers the purchase price of new equipment relative to the price of consumption goods and structures. As a result, households reallocate their expenditures, so that they purchase relatively more equipment goods. However, the positive wealth effect produced by this shock is sufficiently large to offset the substitution out of consumption, and therefore consumption rises. The rise in equipment investment and consumption exceed the fall in the production of structures, and therefore output increases. Furthermore, output, consumption and investment in structures respond positively in future periods, when new equipment goods become available for production.

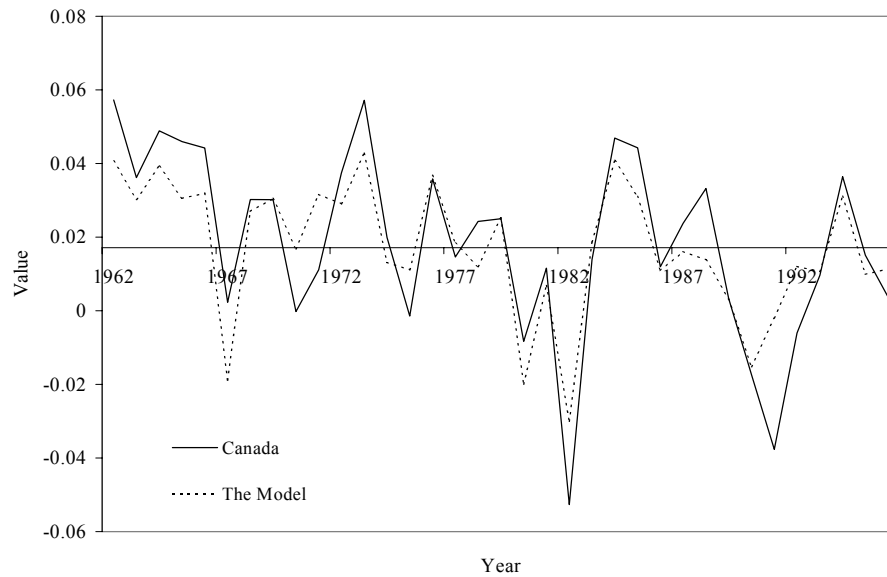
Since both types of shocks move hours worked, consumption and investment in the same direction as output; these variables are all procyclical, as they are in the data. However, given the dynamics just described, it was surprising to find that output and the relative price have a positive correlation in both the model and the data. Since lower prices lead to higher output levels, a positive correlation between the relative price and the level of output presents a puzzle. In order to explain this correlation, it is necessary to account for the timing of the technology disturbances. Recall, output fluctuations in the model were generated using the actual technology disturbances from the Canadian economy. Thus, in both the data and the model, the rate of RNT slowed in 1974, whereas the rate of IST increased. Furthermore, since RNT was low during the post-1974 period, output was low. As a result, in our model output was low when the quality of new capital was high and when relative prices were low, as it was in the data. This is true despite the fact that rapid advancements in investment-specific technology had negative effects on prices and positive effects on output during the later period.

3.2. Economic Growth

The average annual rates of output growth in Canada and the model are displayed in Figure 1 and Table 4. The model appears to track the growth rate of real GDP per capita in Canada fairly closely. The statistics displayed in Table 4 indicate that there is a growth slowdown in the model, however, it is less severe compared to what was actually experienced in Canada. In the data, the rate of output growth fell by 2.24 percentage points - from 3.34% to 1.09%. Whereas in the model it declined by only 1.60 percentage points - from 2.76% to 1.16%. The model cannot fully account for the very rapid growth experienced in Canada between 1961 and 1973. This is an implication of the fact that output in the model fluctuates less than it does in the Canadian data.

Table 4. Annual Growth Rates: Real GDP Per Capita

	1961-73	1974-96	1961-96
Canadian Economy	3.34%	1.09%	1.86%
Model Economy	2.76%	1.16%	1.71%

**Figure 1.** Annual Growth Rates: Real GDP Per Capita

To help understand why output growth slowed in 1974, it is useful to decompose the growth rate of output into various components. Conventional growth accounting involves the decomposition of the growth rate of output into the growth rates of factor inputs and productivity, as follows:

$$\frac{\Delta y}{y} = \Delta TFP + \alpha_n \frac{\Delta n}{n} + \alpha_s \frac{\Delta s}{s} + \alpha_e \frac{\Delta e}{e}, \quad (19)$$

where ΔTFP denotes the rate of total factor productivity growth. Readers must not interpret the rate of TFP growth as equivalent to the rate of RNT growth. The former is calculated from output as measured by Equation (16); whereas the latter is calculated from expenditures as measured by Equation (14), so that

$$\Delta RNT = \frac{\Delta F}{F} - \left(\alpha_n \frac{\Delta n}{n} + \alpha_s \frac{\Delta s}{s} + \alpha_e \frac{\Delta e}{e} \right). \quad (20)$$

In both equations (19) and (20) the measure of inputs to production are identical. It is only the measure of output that differs with Equation (20) having the investment-specific improvements in quality removed.⁴ Table 5 presents the results of a conventional growth accounting exercise.

Table 5. Conventional Growth Accounting

Economy	Share Weighted Growth Rates				
	Hours (n)	Structures (s)	Equipment (e)	TFP	Total (y)
Canada					
1961-73	0.39	0.32	0.88	1.75	3.34
1974-96	-0.12	0.20	0.84	0.17	1.09
1961-96	0.05	0.24	0.85	0.71	1.86
Model					
1961-73	-0.02	0.39	0.44	1.96	2.76
1974-96	-0.01	0.16	0.97	0.04	1.16
1961-96	-0.01	0.24	0.79	0.70	1.71

The conventional growth accounting exercise has identified three factors that contributed to the slow down in Canadian output growth: (i) a fall in the growth rate of the labor input (i.e. a decline in hours worked per capita), (ii) a reduction in the rate of accumulation of structures and (iii) a lower rate of productivity growth. The time series generated for the artificial economy also displays a slow down in the growth rate of structures and productivity after 1974. Notice, however, that in the artificial economy the productivity slowdown is slightly more severe than it is in the Canadian economy. In part, the TFP series in the model is compensating for the fact that hours worked is relatively stable.

⁴ For a discussion of the components of output used in these calculations readers are referred back to section 2.5. For a detailed discussion of the contributions of RNT and IST to TFP growth readers are referred to Carlaw and Kosempel (2000). They identify two channels through which IST affects total factor productivity (TFP). First, IST improves the quality of capital goods, and therefore enables more effective units of output to be produced per unit of capital and labor employed. Second, IST reduces the price of new equipment relative to the price of other goods, and therefore it provides an incentive for economic agents to reallocate their expenditures away from consumption goods and structures and towards equipment goods. In other words, productivity increases partly because of better production technologies in the capital goods producing sector and partly because more resources get allocated to the more productive sector.

The conventional growth accounting analysis fails to provide answers to a number of important questions. First, why did the growth rates of the factor inputs and the rate of productivity growth decline? Second, how sensitive is the rate of GDP growth to changes in RNT and IST? The remainder of this section is devoted to answering these questions.

Recalling the impulse responses to the technology shocks that were described in Section 4.1 can solve the first question. Recall, a negative RNT shock produced a decline in factor productivity, and this in turn lowered the rate of return to a capital investment. As such, a slow down in the rate of RNT growth after 1974 would have produced a decline in TFP growth and a fall in the rate of accumulation of capital. In comparison, in the model a positive IST shock allowed more equipment to be produced per unit of capital and labor employed, and lowered the relative price of equipment. As such, a rise in the rate of IST growth after 1974 would have produced a rise in the productivity of the factors employed in the manufacturing of equipment goods, and a rise in the rate of accumulation of equipment. Note that changes to the time series behavior of the two types of technology after 1974 had opposite effects on the incentives to accumulate equipment and TFP. This may explain why the accumulation of equipment did not slow down as much as structures after 1974. The predictions of the model also indicate that the rise in the rate of IST growth was not sufficiently strong enough to offset the decline the rate of RNT growth, and therefore TFP growth slowed after 1974. The fact that TFP is more sensitive to RNT than it is to IST should not seem too surprising, after all improvements in IST only affect the capital good sector, whereas improvements in RNT affect all sectors.

In both Canada and the model, growth in the factor inputs and TFP represent induced responses to RNT and IST. Since the two technologies affect the rate of capital accumulation and the rate of productivity growth, they will also affect the rate of output growth. In fact, without technological change a modern industrial economy, such as Canada, would experience no output growth. In order to isolate the contribution of a particular technology to output growth, each technology series was filtered through the model separately. The results are summarized in Table 6.

Table 6. Contribution of Technologies to the Rate of GDP Growth

	1961-73	1974-96	1961-96
Amount Contributed (percentage points):			
(A) Investment-Specific ($g_A = 0$)	0.24	1.17	0.85
(B) Residual-Neutral ($g_q = 0$)	2.58	-0.03	0.87
(C) Combined ¹⁾	2.76	1.16	1.71
Percentage of Total			
(D) Investment-Specific (A/C)*100	9	100	50
(E) Residual-Neutral (B/C)*100	91	0	50

Notes: ¹⁾ Note that adding up the contributions of the two technologies yields a growth rate that differs slightly from the estimates in this row. These differences are an implication of the fact that when both technologies operate together they have some offsetting effects on the rate of output growth.

The model predicts that over the entire 1961-96 period IST accounted for 50 percent of Canada's output growth. The remaining 50 percent is attributed to RNT. It is evident that there has been a considerable shift in the sources of growth. Between 1961 and 1973, only 9 percent of growth could be explained by improvements in investment-specific technology. However, since the mid-1970s the contribution of IST to the rate of output growth increased significantly. Today, IST accounts for virtually all of Canada's economic gains.

The results also indicate that the increase in the rate of IST over the post-1974 period produced an increase in the rate of output growth of 0.93 percentage points, *ceteris paribus*. However, this gain was more than offset by the reduction in the rate of RNT, which produced a decline in the rate of output growth of 2.61 percentage points, *ceteris paribus*. The net effect was a fall in the rate of output growth by 1.60 percentage points.

4. CONCLUSION

This paper quantified the contributions of RNT and IST to the growth rate of Canadian GDP per capita over selected periods. The results are as follows: IST was found to account for approximately 50 percent of the growth in GDP over the entire 1961-96 period, 9 percent over the pre-1974 period and 100 percent over the post-1974 period. RNT accounted for the remainder in each period. The increase observed in the rate of IST over the post-1974 period produced an increase in the rate of output growth of 0.93 percentage points, *ceteris paribus*. However, this gain was more than offset by the reduction in the rate of RNT, which produced a decline in the rate of output growth of 2.61 percentage points, *ceteris paribus*. The net effect was a fall in the rate of output growth by 1.60 percentage points.

There is one final point of interest that the model has not addressed. There is a negative correlation between rates of IST and RNT of -0.53, which suggests the possibility that the process of embodying new technologies has implications for general productivity. There is a large literature on the issue of growth driven by technological change, which argues that the process of investment in new technology requires subsequent investment in complementary new skills and human capital, as well as in other complementary capital goods (e.g., Lipsey, Bekar and Carlaw (1998), David (1991), Rosenberg (1982)). Our calculations may be evidence of this effect. RNT is at least partially a measure of labor productivity, and the fact that we occasionally observe negative RNT at the same time we observe positive IST may be a reflection of a skill set embodied in labor which is not compatible with the technology being embodied in new capital goods.

Is the negative relationship between IST and RNT evidence of a more fundamental relationship? Nothing in the analysis conducted here tells us the answer to this question, but it is a line of research that we wish to pursue. We believe that there is sufficient circumstantial evidence to warrant research into the relationships between IST and RNT and IST and TFP. Particularly since this has policy implications for long-term economic

growth in Canada. If it is possible to verify the existence of a complementary relationship between technological embodiment in human as well as physical capital, then there is more advice for policy than the standard neoclassical prescription that investment and saving are good for growth. In particular, while capital investment is necessary, it may not be sufficient. Investment in physical and human capital must be complimentary to each other.

APPENDIX

Data Definitions and Sources

A description of the data and macroeconomic variables used in this study is provided below. All expenditures and factor inputs were deflated by the 16+ population. All dollar values are based on 1992 prices. Data is from the Canadian Socio-economic Information and Management System Database (CANSIM).

Output (y): real gross domestic product (D22467) net of gross housing product (measured by gross imputed rents D22923 and gross paid rents D22924).

Consumption (c): real expenditures on consumer semi-durables (D22439), non-durables (D22440) and services (D22441) net of gross housing product.

Investment in Structures (i_s): real business gross fixed capital formation in structures (D22449).

Investment in Equipment (qi_e): real business gross fixed capital formation in machinery and equipment (D22450).

Total Expenditures (F): calculated as output (y) less investment in equipment (qi_e) plus expenditures on equipment (i_e). Here expenditures on equipment are measured in terms of forgone consumption, that is, they have been deflated by the implicit price deflator for consumer non-durables, semi-durables and services.

Hours Worked (n): total hours at work in non-agricultural industries. Calculated from total hours at work (I190301) less hours worked in agriculture (I190302).

Capital Inputs (s and e): Time series for the capital stocks were estimated by iterating on their respective laws of motion. The initial values were set at their balanced growth levels.

Relative Price (p): the ratio of the implicit price deflator for real business gross fixed capital formation in machinery and equipment to the implicit price deflator for consumer semi-durables, non-durables and services.

Investment-Specific Technology (q): the reciprocal of the relative price (base = 1992).

The Rate of Residual-Neutral Technological Change: calculated as the growth rate of total expenditures (F) less the share weighted growth rates of the labor and capital inputs.

The Rate of Total Factor Productivity Growth: calculated as the growth rate of output (y) less the share weighted growth rates of the labor and capital inputs. Recall, output is measured in effective units, and therefore it includes quality components. Expenditures are measured in consumption equivalents, and therefore they exclude quality components. Hence, there is a difference between RNT and TFP.

16+ Population: Total population (D892268 for pre-1971 and C892268 for post-1971) less population under age 15 (D892541 for pre-1971 and C892541 for post-1971)

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Mailing Address: Department of Economics, University of Guelph, Guelph, Ontario, N1G 2W1, Canada. Tel: 519-824-4120 ext. 53948, Fax: 519-763-8497. E-mail: kosempel@uoguelph.ca

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