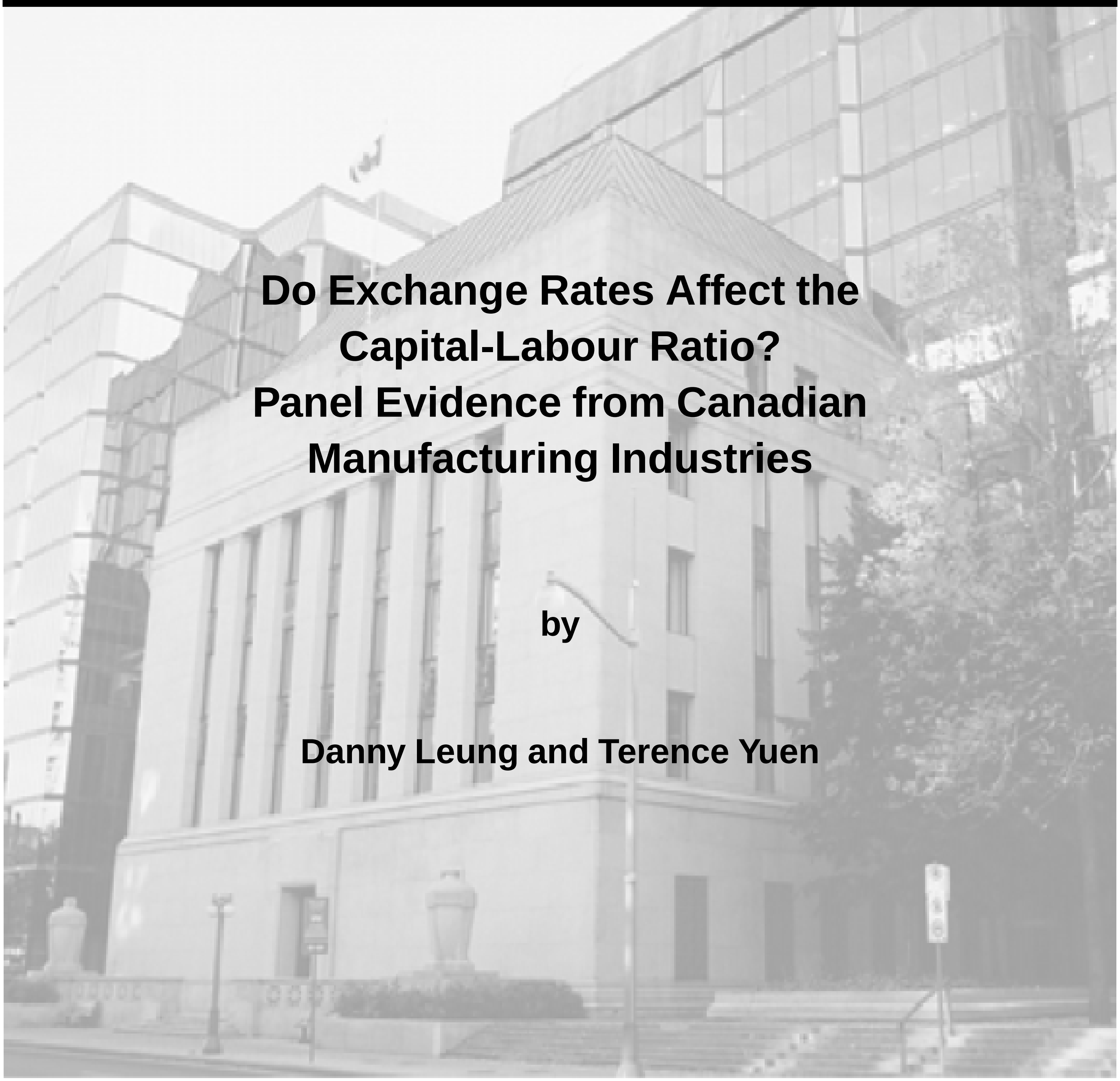
Bank of Canada   Banque du Canada

Working Paper 2005-12 / Document de travail 2005-12



Do Exchange Rates Affect the Capital-Labour Ratio? Panel Evidence from Canadian Manufacturing Industries

by

Danny Leung and Terence Yuen

ISSN 1192-5434

Printed in Canada on recycled paper

Bank of Canada Working Paper 2005-12

2005 April

Do Exchange Rates Affect the Capital-Labour Ratio? Panel Evidence from Canadian Manufacturing Industries

by

Danny Leung and Terence Yuen

Research Department
Bank of Canada
Ottawa, Ontario, Canada K1A 0G9
dleung@bankofcanada.ca
tyuen@bankofcanada.ca

Contents

Acknowledgements

We would like to thank Bob Amano, Allan Crawford, Bob Fay, John Helliwell, Larry Schembri, and seminar participants at the Bank of Canada, the 2004 Canadian Economic Association Meetings, and Industry Canada for helpful comments. We would also like to thank John Baldwin, of Statistics Canada, for providing access to the data.

Abstract

Using industry-level data for Canadian manufacturing industries from 1981 to 1997, the authors find empirical evidence of a negative relationship between the capital-labour ratio and the user cost of capital relative to the price of labour. A 10 per cent increase in the user cost of the machinery and equipment (M&E) relative to the price of labour results in a 3.3 per cent decrease in the M&E-labour ratio in the long run. Assuming complete exchange rate pass-through into imported M&E prices, the maximum effect of a permanent 10 per cent depreciation in the exchange rate is a 5.2 per cent increase in the user cost of M&E, and a 1.7 per cent decline in the M&E-labour ratio. This result implies that the cumulative growth of the M&E-labour ratio during the 1991–97 period would have been 2.3 percentage points higher had the dollar not depreciated. This may appear to be significant, but, considering that M&E as a share of total capital and capital's share of nominal output are both approximately one-third, in terms of a simple growth accounting framework, the effect on labour productivity is small.

JEL classification: F4
Bank classification: Exchange rates; Productivity

Résumé

En utilisant des données sectorielles sur les industries manufacturières du Canada pour la période de 1981 à 1997, les auteurs obtiennent des résultats empiriques qui montrent la présence d'une relation négative entre le ratio capital/travail et le coût d'usage du capital par rapport au coût du travail. Une hausse de 10 % du coût d'usage des machines et du matériel (MM) comparativement au coût du travail entraîne une diminution de 3,3 % du ratio MM/travail à long terme. En supposant que les variations du taux de change sont pleinement transmises aux prix des machines et du matériel importés, une dépréciation permanente de 10 % du taux de change a comme effet maximal une augmentation de 5,2 % du coût d'usage des machines et du matériel, et une baisse de 1,7 % du ratio MM/travail. Ce résultat implique que la croissance cumulative du ratio MM/travail aurait été de 2,3 points de pourcentage plus élevée durant la période de 1991 à 1997, n'eût été la dépréciation du dollar canadien. Cet écart peut sembler considérable; cependant, comme les machines et le matériel représentent approximativement un tiers du capital total, et le capital, environ un tiers également de la production nominale, l'effet sur la productivité du travail est limité, selon un cadre simple de comptabilité de la croissance.

Classification JEL : F4
Classification de la Banque : Taux de change; Productivité

1. Introduction

The revival of U.S. productivity in the late 1990s led to a large volume of research that examines the contribution of information technology to productivity growth.[1] Although most of the work focuses on the high-tech revolution, it is important to explore the role of other determinants of productivity. In particular, for a small open economy, there is a potential link between exchange rate movements and productivity. A common argument is that the effects of exchange rate pass-through influence factor demands by changing the relative price between domestic and foreign inputs. In the case of an exchange rate depreciation, firms would substitute capital for labour in response to the rising price of imported capital. This, in turn, would have a negative impact on labour productivity as the capital-labour ratio fell.

The extent to which the exchange rate affects productivity remains an empirical question. As a small open economy with increasing U.S. trade exposure and large exchange rate fluctuations over the past two decades, Canada provides an excellent environment in which to address this issue. A striking study by McCallum (1999) shows that the declining relative labour productivity of Canada's manufacturing sector is highly correlated to the two-year lag of the nominal Canada-U.S. exchange rate over the 1977–97 period. He suggests that the exchange rate depreciation may be a contributing factor to the divergence in productivity growth between Canada and the United States. Empirical evidence offered in the existing literature,[2] however, is based on some casual relationships between the exchange rate and productivity. These types of models do not test the transmission mechanism through which exchange rates affect productivity. To shed light on this issue, a logical approach is to develop a framework in which factor inputs are adjusted optimally in response to exchange rate shocks.

Related studies of the exchange rate effects on dynamic factor demands have two shortcomings that hamper insight into long-run productivity, and, in particular, the capital-labour ratio. First, they focus exclusively on the adjustment of a single factor and assume no adjustment costs on other factors. For example, Campa and Goldberg (2001)

[1] See, for example, Brynjolfsson and Hitt (2000), Oliner and Sichel (2000), and Stiroh (2001).

[2] See Dupuis and Tessier (2000).

and Dekle (1998) concentrate on the impact on employment,[3] and Campa and Goldberg (1995, 1999) and Harchaoui, Tarkhani, and Yuen (2003) focus on investment decisions.[4] Second, the majority of these studies concentrate on the partial adjustment path without imputing the long-run elasticities of input demands.

In this paper, we adopt a dynamic framework with multiple quasi-fixed factors to examine the effects of exchange rates on the capital-labour ratio for the manufacturing sector in Canada. Consistent with the theory, our empirical results are in support of a negative relationship between the machinery and equipment (M&E)-labour ratio and the user cost of M&E relative to the price of labour. The long-run elasticity is around -0.33; that is, a 10 per cent increase in the user cost of M&E relative to the price of labour results in a 3.3 per cent decrease in the M&E-labour ratio in the long run. Moreover, there is evidence that the substitution between labour and capital is much more responsive to changes in the price of labour than the user cost. A plausible explanation is that wages are less volatile than the user cost of capital. As a result, movements in wages are likely to be perceived as permanent, whereas changes in the user cost are mainly seen as transitory.

Assuming complete exchange rate pass-through into imported M&E prices, the approximate effect of a permanent 10 per cent depreciation in the exchange rate is a 5.2 per cent increase in the price and user cost of M&E. This translates into a 1.7 per cent decline in the M&E-labour ratio. While the magnitude of the effect of the exchange rate is not small, it is not sufficiently large to drive the observed movements in the relative price of M&E or the M&E-labour ratio. We find that the effects of the depreciation in the early 1980s were offset by the appreciation in the late 1980s. The depreciation in the 1990s then decreased the cumulative growth in the M&E-labour ratio by 2.3 percentage points during the 1991–97 period. This upper-bound estimate may appear to be significant, but considering that M&E as a share of total capital and capital's share of

[3] They find conflicting evidence on employment adjustments to exchange rate movements for the U.S. and Japan manufacturing industries.

[4] They find supportive evidence that investment sensitivity to exchange rate movements varies positively to revenue channels.

nominal output are both roughly one-third, in terms of a simple growth accounting framework, the effect on labour productivity is small.

This paper is organized as follows. Section 2 describes the theoretical framework. Section 3 describes the data set. Section 4 provides econometric specifications and empirical results. Section 5 offers some conclusions.

2. Theoretical Framework

2.1 The link between exchange rates and labour productivity

As Lafrance and Schembri (1999–2000) discuss, a proposition that supports a link between the exchange rate and productivity is the factor-cost hypothesis.[5] In general, labour productivity depends on total factor productivity and the ratio of capital to labour input. Movements in the real exchange rate affect total factor productivity by changing the cost of imported capital, and thereby influencing the decisions on investment in new capital, which typically embodies new technology. Also, labour productivity is affected due to changes in the relative price of capital to labour that determines the long-run capital-labour ratio. In this paper, we assume that total factor productivity is exogenous and focus on the relationship between labour productivity and the capital-labour ratio.

Consider a standard production function in which output (*Y*) is produced using capital (*K*) and labour (*L*). With the assumption of constant returns to scale, labour productivity defined as output per unit of labour input can be written as:

$$Y/L = AF(K/L), \tag{1}$$

where *A* is exogenous total factor productivity. Equation (1) shows that the growth in labour productivity is driven by two factors: (i) the change in total factor productivity, and (ii) the change in the capital-labour ratio. A 1 per cent change in total factor productivity leads to a 1 per cent change in labour productivity. In addition, a rise in the

[5] Two other propositions discussed in Lafrance and Schembri (1999–2000) are the Balassa-Samuelson model and the hypothesis of exchange rate sheltering.

capital-labour ratio, also known as capital deepening, will raise the level of labour productivity as $\frac{\partial F(K/L)}{\partial K/L} > 0$.[6]

An important factor that influences the capital-labour ratio is the price of capital relative to the price of labour. Intuitively, when labour becomes more expensive relative to capital, capital is substituted for labour. To establish a negative relationship between the capital-labour ratio and relative input price in a neoclassical framework, we employ a constant elasticity of substitution (CES) production function, $F(K,L) = A\left(a_K K^{-r} + a_L L^{-r}\right)^{-1/r}$. In the absence of adjustment cost, inputs are fully adjusted such that the marginal revenue product equals the marginal cost. Assuming that input markets are competitive,

$$\frac{a_K}{a_L}\left(\frac{K}{L}\right)^{-(1+r)} = \frac{r}{w}, \tag{2}$$

where r and w denote the user cost of K and the wage rate of L, respectively. The equilibrium condition (2) states that the rate of technical substitution on the left-hand side of the equation is equal to the input-price ratio. Note that equation (2) is linear in logs,

$$\log\left(\frac{K}{L}\right) = \frac{1}{1+r}\log\left(\frac{a_K}{a_L}\right) - \frac{1}{1+r}\log\left(\frac{r}{w}\right). \tag{3}$$

It is clear that the optimal capital-labour ratio, K/L, in equation (3) is determined by the ratio of the technology efficiency parameters, a_K/a_L, and the relative price of capital, r/w. As capital becomes more productive relative to labour (i.e., a_K/a_L increases), firms substitute capital for labour and the capital-labour ratio increases. Additionally, more expensive capital leads to a rise in r/w, which has a negative impact on K/L due to the substitution effect. In the CES case, the elasticity of the capital-labour ratio with respect

---

[6] One might argue that changes in the capital-labour ratio, particularly capital deepening in information and computer technology (ICT), would have an indirect impact on labour productivity through the total factor productivity channel. Recent studies suggest that there exists a positive correlation between ICT investment and total factor productivity growth (e.g., Nordhaus 2002 and Parham 2002). As noted, we assume that total factor productivity is exogenous in our framework.

to the relative input price $\left(\frac{\partial \log K/L}{\partial \log r/w}\right)$ is the elasticity of substitution, $1/1+r$. In other words, a 1 per cent increase in *r/w* lowers *K/L* by $1/1+r$ per cent.

The main channel through which the exchange rate can affect labour productivity is through changes in the relative input price. Assuming that the amount of imported labour is small, the exchange rate's impact should be primarily on the price of investment, *q*. The amount by which the price of investment changes depends on the fraction of capital imported and the degree of exchange rate pass-through into imported capital prices. For example, assuming full pass-through, and given that the imported share of capital is 0.5, a 1 per cent depreciation in the exchange rate leads to a 0.5 per cent increase in the price of investment. A change in the price of investment then affects the user cost of capital. Harchaoui and Tarkhani (2002) show that the user cost of capital is related to the price of investment in the following way:

$$r_t = q_{t-1}(v_t + d) - (q_t - q_{t-1}), \tag{4}$$

where v is the rate of return required by the firm and d is the depreciation rate.[7] The user cost of capital is equal to the opportunity cost of employing the capital, plus the cost of depreciation, minus the capital gain. The long-term effect of a permanent depreciation of the exchange rate is a rise in the opportunity cost and cost of depreciation. The capital gain term has only a temporary effect on the user cost. Thus, in the long run, the price of investment and user cost of capital are approximately proportional. A 0.5 per cent increase in the price of investment leads to a 0.5 per cent increase in the user cost. Assuming that labour and capital are substitutes in the production function, profit-maximizing firms will increase their demand for domestic labour as the exchange rate

[7] The measure of the user cost of capital used in the empirical section of this paper takes taxes and investment credits into account. The appendix shows the expression for the user cost that includes these considerations. User cost not including taxes is shown here for simplicity only. It does not affect the arguments made in this section.

depreciates and the user cost of capital rises.[8] This lowers the capital-labour ratio, which, in turn, has an adverse effect on labour productivity.

There is a second channel in which exchange rate changes can affect the capital-labour ratio. The exchange rate affects the price of domestic output relative to foreign output. As the exchange rate depreciates, demand for domestic output increases as the product becomes relatively cheaper. Factor demands for both labour and investment rise as a result of the increase in marginal revenue product. The impact on the capital-labour ratio is ambiguous, depending on the production structure. If the production function is homothetic, changes in output would have no impact on the capital-labour ratio.

2.2 Capital-labour ratio in a dynamic factor demand framework

It is well known in the literature that factor inputs are quasi-fixed in the short run and, hence, their response to exogenous shocks is not instantaneous. Most of the existing studies focus exclusively on the adjustment of a single factor, either capital or employment, and assume no adjustment costs on other factors.[9] In this section, we derive a dynamic factor demand model where both capital and labour are quasi-fixed. Firms maximize their expected future profits such that the present value of expected future marginal revenue product from an additional unit of input is equal to the marginal cost, which includes the input price and the marginal adjustment cost. Nickell (1986) shows that the solution of this optimization problem can be expressed as dynamic paths, where quasi-fixed factors adjust gradually towards their long-run optimal levels that would exist in the absence of adjustment costs. The size of the adjustment costs, however, plays an important role in determining the speed of the reallocation process. The higher the adjustment cost, the slower the speed to the long-run equilibrium. With the assumption of quadratic adjustment costs, the adjustment dynamics of the capital-labour ratio can be summarized as a log-linear function. In this case, the capital-labour ratio at time t depends on its lagged values at t-1 and t-2, as well as the long-run optimal ratio, $\tilde{K}/\tilde{L}$.

---

[8] If imported and domestic capital are substitutable, then the effect of an exchange rate depreciation on the capital-labour ratio would be lessened as firms substitute towards both labour and domestic capital.

[9] Hamermesh and Pfann (1996) provide an extensive survey of the literature on dynamic factor demands.

Changes in the relative input price, r/w, enter the model because they affect the current capital-labour ratio by influencing $\tilde{K}/\tilde{L}$.

More formally,[10] let the representative firm maximize the expected present value of all future profits,

$$p_t = \max_{K_{t+t}, L_{t+t}} E_t \left[\sum_{t=0}^{\infty} b^t G(K_{t+t}, L_{t+t}) - C_K(\Delta K_{t+t}) - C_L(\Delta L_{t+t}) \right], \tag{5}$$

where *ß* is the discount factor, which is assumed to be constant over time. The operator, E_t, is the conditional expectation on all the information available at time t. The firm's profit net of adjustment costs at period t is $G(K_t, L_t) = p_t Y_t - r_t K_t - w_t L_t$, with p denoting the output price of Y.

Without loss of generality,[11] the adjustment cost structure of capital and labour is assumed to take a quadratic form that simplifies the empirical implementation of the partial-adjustment equations:

$$C_K(\Delta K) = \frac{q_K (\Delta K)^2}{2}, \tag{6a}$$

$$C_L(\Delta L) = \frac{q_L (\Delta L)^2}{2}, \tag{6b}$$

where ΔK and ΔL represent changes in capital and labour, respectively. The size of the adjustment cost is determined by the parameters q_K and q_L.

Solving the maximization problem (5) subject to (6) yields the optimal demands for K and L that can be expressed as a well-known partial-adjustment equation:

$$\begin{bmatrix} L_t \\ K_t \end{bmatrix} = V \begin{bmatrix} L_{t-1} \\ K_{t-1} \end{bmatrix} + \sum_{t=0}^{\infty} (bV)^t [I - bV][I - V] E_t \left(\begin{bmatrix} \tilde{L}_{t+t} \\ \tilde{K}_{t+t} \end{bmatrix} \right), \tag{7}$$

---

[10] See the appendix for details of the complete derivation.

[11] It is straightforward to extend this model to flexible inputs; the extension does not change the main results hereafter.

where $\tilde{K}$ and $\tilde{L}$ are the long-run equilibrium levels of factor inputs, which are equivalent to the solution of the static problem with no adjustment cost. Generally, the matrix $V=\begin{bmatrix} v_{L1} & v_{L2} \\ v_{K2} & v_{K1} \end{bmatrix}$ can be interpreted as the speed of adjustment and it is increasing with the adjustment cost parameter, q. A higher q implies a slower adjustment to the long-run optimal level.

To illustrate the adjustment path of L and K in an intuitive way, it is helpful to consider a case where all shocks are permanent; i.e., $E_t\left(\tilde{K}_{t+t}\right)=\tilde{K}$ and $E_t\left(\tilde{L}_{t+t}\right)=\tilde{L}$. We can then ignore the expectation operations, and equation (7) can be simplified to

$$\begin{bmatrix} L_t \\ K_t \end{bmatrix} = V\begin{bmatrix} L_{t-1} \\ K_{t-1} \end{bmatrix} + [I-V]\begin{bmatrix} \tilde{L} \\ \tilde{K} \end{bmatrix}. \tag{8}$$

Compared with a model that has only one quasi-fixed factor,[12] the adjustment dynamics in equation (8) follow a more complicated structure, because the adjustment of one factor of production also relates to other factor inputs.[13] The adjustments of K_t and L_t depend on both K_{t-1} and L_{t-1}, as well as $\tilde{K}$ and $\tilde{L}$. Thus, for the convergence rates of K and L to the long-run equilibrium,

$$\frac{\Delta L_t}{\left(\tilde{L}-L_{t-1}\right)} = a_t^L = \left(1-v_{L1}\right) - v_{L2}\left(\frac{\tilde{K}-K_{t-1}}{\tilde{L}-L_{t-1}}\right), \tag{9a}$$

$$\frac{\Delta K_t}{\left(\tilde{K}-K_{t-1}\right)} = a_t^K = \left(1-v_{K1}\right) - v_{K2}\left(\frac{\tilde{L}-L_{t-1}}{\tilde{K}-K_{t-1}}\right). \tag{9b}$$

---

[12] For example, when labour is flexible with $q_L = 0$, the demand for capital at t is a simple linear combination of K_{t-1} and $\tilde{K}$, and it is not related to other inputs, $K_t = vK_{t-1} + (1-v)\tilde{K}$. Moreover, the adjustment to the long-run equilibrium follows a constant convergence rate: $\frac{\Delta K_t}{\left(\tilde{K}-K_{t-1}\right)} = a$, where $a = (1-v)$.

[13] In general, V is not a diagonal matrix, except in some restrictive production functions.

Since the ratio $\tilde{K} - K_{t-1} / \tilde{L} - L_{t-1}$ changes over time, the convergence rates, a_t^L and a_t^K, are not constant, but time-varying in equations (9a) and (9b). In the case where labour inputs have adjustment costs that are lower than capital (i.e., $q_L < q_K$), the model predicts that the speed of adjustment to the long-run optimal level is faster in labour, such that $a_t^L > a_t^K$. This implies a rising ratio of $\tilde{K} - K_{t-1} / \tilde{L} - L_{t-1}$, such that the convergence rate of labour inputs (a_t^L) decreases over time, whereas a_t^K increases over time.

To derive an expression for the capital-labour ratio, it is convenient to take a log approximation of equation (8).[14] Rearranging equation (8) in logs,[15]

$$\log\left(\frac{K}{L}\right)_t = \left(v_{L1} + v_{K1}\right)\log\left(\frac{K}{L}\right)_{t-1} - \left(v_{L1}v_{K1} - v_{L2}v_{K2}\right)\log\left(\frac{K}{L}\right)_{t-2} + \left[\left(1 - v_{L1}\right)\left(1 - v_{K1}\right) - v_{L2}v_{K2}\right]\log\left(\frac{\tilde{K}}{\tilde{L}}\right). \quad (10)$$

Equation (10) shows that the adjustment dynamics of the capital-labour ratio can be summarized as a log-linear function. The capital-labour ratio at time t depends on its lagged values at t-1 and t-2, as well as the long-run equilibrium levels of the capital-labour ratio, $\tilde{K}/\tilde{L}$. Changes in the relative price of capital (r/w) affect the current capital-labour ratio because $\tilde{K}/\tilde{L}$ is determined by r/w in a CES production function.

To summarize, let us look at a numerical example in which labour adjustments are more flexible than capital with $V = \begin{bmatrix} 0.5 & 0.05 \\ 0.15 & 0.8 \end{bmatrix}$. Suppose there is a permanent decline in the user cost due to an exchange rate appreciation. Then, the relative price of capital (r/w) falls and the long-run capital-labour ratio $\tilde{K}/\tilde{L}$ rises. As a result, firms have to increase their capital-labour ratio by 10 per cent to reach the long-run equilibrium.[16]

---

[14] This is appropriate as long as the deviations of L, K, $\tilde{L}$, and $\tilde{K}$ from some average levels are small. Note that, for any x, $(x/\bar{x}) - 1 \cong \log(x/\bar{x})$ if $x - \bar{x}$ is small.

[15] See the appendix for the intermediate steps.

[16] In this example, log K_{t-1} = 1, log L_{t-1} = 1, log $(K/L)_{t-1}$ = 0, log $\tilde{L}$ = 1.1, log $\tilde{K}$ = 1.2, and log $\tilde{K}/\tilde{L}$ = 0.1.

Figure 1 shows the adjustment dynamics of *K*/*L*. Note that the transition from K/L_{t-1} to $\tilde{K}/\tilde{L}$ does not necessarily follow a monotonic pattern. If the cost of adjusting labour is very small, such that v_{K1} is much larger than v_{L1}, the capital-labour ratio will fall initially before it starts to converge to the long-run equilibrium. Conversely, an exchange rate depreciation could have a negative impact on $\tilde{K}/\tilde{L}$, requiring firms to lower the capital-labour ratio, in which case the adjustment path would be the mirror image of Figure 1.

3. Data

3.1 Aggregate patterns

The empirical analysis in this paper is conducted on annual data (1981–97) from the Canadian Productivity Accounts for 21 manufacturing industries.[17] Capital inputs (constant quality indexes of capital services) are derived from the stock of physical assets, which include machinery and equipment, structures, inventories, and land.[18] Labour inputs are quality-adjusted hours worked.[19] Figure 2 shows the evolution of the capital-labour ratio and its relative price (user cost of capital over the price of labour) for all 21 manufacturing industries over the sample period.[20] Over the period 1981–97, the capital-labour ratio increased by approximately 20 per cent. A large fraction of this increase took place between 1988 and 1991. While the relative price of capital has also increased over time, in many of the years its movements have been opposite to those of the capital-labour ratio. For example, Figure 2 confirms the general perception that the relative price of capital increased and the capital-labour ratio fell during the first half of

[17] The manufacturing industries are according to the 1980 Standard Industrial Classification (SIC). The original classification includes 22 manufacturing industries. The refined petroleum and coal products industry is excluded from our sample due to missing data. For details on each industry, see Table 1.

[18] See Harchaoui and Tarkhani (2002) for more detail on how capital input is constructed.

[19] See Gu et al. (2002) for more detail on how labour input is constructed.

[20] The capital-labour ratio for the 21 manufacturing industries is obtained by aggregating the growth rates of capital and labour separately. Capital growth rates in period *t* are aggregated using each industry's average nominal cost of capital for *t* and *t*-1 as weights. The growth rate of labour input for the 21 manufacturing industries is similarly calculated. The difference in the aggregate capital and labour input growth rates is then used to create indexes. The relative price of capital for the 21 manufacturing industries is computed in the same way.

the 1990s. Other periods in which the capital-labour ratio and the relative price move in opposite directions include the 1981–84 period, and most evidently the 1988–91 period.

Since Rao, Tang, and Wang (2003) suggest that labour productivity depends more on M&E than on land or structures, Figure 3 shows the changes in the M&E-labour ratio and its relative price. Figure 3 is similar to Figure 2 in that the relative price of M&E moves opposite to that of the M&E-labour ratio in many periods. The clear exceptions are during the 1985–87 and 1994–95 periods, when both the relative price and relative quantity rise.

M&E can be further disaggregated into information and communications technology (ICT) and other M&E. Figure 4 shows that the amount of ICT capital used in the manufacturing industry has grown considerably between 1981 and 1997. The ICT-labour ratio has increased by over a factor of ten. On the other hand, the relative price of ICT has fallen by approximately 60 per cent. Since the ICT-labour ratio has been increasing throughout the sample period and the relative price of ICT has generally been declining, it may be difficult to separate the effects of the decline in the relative price from a technological-induced increase in the amount of ICT used over time. Figure 5 shows the other M&E-labour ratio and its relative price. Figure 5 closely resembles Figure 3. This underlines the fact that, while ICT capital has grown substantially, it is still a relatively small fraction of M&E.[21]

Although Figures 2 to 5 suggest that the relative price of capital likely explains some of the movements in the capital-labour ratio, to establish a link between exchange rate movements and the capital-labour ratio, one must show that the relative price of capital is related to the exchange rate. Figure 6 shows the evolution of the relative price of capital and the Canada-U.S. bilateral exchange rate. The exchange rate and the relative price of capital appear to move together for much of the period. When the exchange rate depreciated during the 1981–86 and 1991–95 periods, the relative price was generally rising. When the exchange rate appreciated during the 1987–90 period, the relative price fell. The magnitude of the fluctuations in the relative price, however, is much greater than that of the exchange rate. This suggests that there are other important factors driving the

[21] In 1981, ICT's share of M&E's cost was 5.4 per cent. By 1997, it had risen to 9.9 per cent.

relative price.[22] The relative prices of M&E, and other M&E, are plotted with the bilateral exchange rate in Figures 7 and 8, respectively. The changes in the relative prices of M&E and other M&E coincide with movements of the exchange rate even more than they do with the overall relative price of capital. On the other hand, the movements in the relative price of ICT in Figure 9 do not appear to coincide with movements in the exchange rate. It is clear, however, that the downward trend in the relative price of ICT slowed when the exchange depreciated in the early 1980s and 1990s.

3.2 Industry-level profiles

Next, we check whether the aggregate patterns observed in Figures 2 and 6 are consistent with the variations across the manufacturing industries. Industry capital-labour ratios are in logs and are indexed to zero in the base year, 1981. Figure 11 shows the evolution of the capital-labour ratio over the sample period. The slope of the fitted linear time trend measures the industry average annual growth rate of the capital-labour ratio. Notably, substantial variation exists across the industry profiles. For example, on average, the capital-labour ratio fell 1.2 per cent per year in fabricated metal products, whereas there was over a 3 per cent annual increase in leather and electrical and electronic products.

It would be interesting to explore whether these divergent patterns in industry capital-labour ratios are related to the evolutions of the relative price of capital (r/w). In Table 1, industries are ranked according to their average annual growth rates of K/L, measured as the slope of the fitted linear time trends in Figure 10. Casual observations suggest that there exists a negative correlation between the growth rates of K/L and r/w. Industries at the bottom of the table with the highest annual growth rates in their K/L ratios tend to experience smaller increases in r/w over the sample period. This negative relationship is further illustrated in the two fitted lines in Figure 11. One is based on the ordinary least squares (OLS) regression, whereas the one with the steeper slope comes from the robust estimator using median regression, which takes into account the

[22] One such factor is aggregate demand: when it is weak, both the exchange rate and price of labour decline. The relative price of capital therefore increases for two reasons. First, the exchange rate depreciation increases the price of investment and user cost of capital. Second, the price of labour falls. In this situation, the movement in the relative price of capital can be greater than the exchange rate. In the

possibility of outlying observations. Consistent with the aggregate pattern, simple statistics at the industry level support the notion that movements in the capital-labour ratio are negatively correlated with the relative price of capital.

4. Empirical Findings

4.1 Baseline specification

The analytical model in section 2 provides a useful framework for empirical estimation. In general, the capital-labour ratio at time t can be written as a log-linear function of the last two periods of the capital-labour ratio and the expected future equilibrium levels of $\tilde{K}/\tilde{L}_{t+j}$. For a CES production, $\tilde{K}/\tilde{L}_{t+j}$ are determined by the future relative prices of capital, r/w_{t+j}. To complete the model, it is necessary to restrict the stochastic process of future input prices. Following Sargent (1978), we assume that future r/w_{t+j} follows an nth-order Markov process. The empirical implementation of equation (10) becomes

$$\log\left(\frac{K}{L}\right)_{it} = B_{0i} + B_{1i}t + B_{21}\log\left(\frac{K}{L}\right)_{it-1} + B_{22}\log\left(\frac{K}{L}\right)_{it-2} +$$

$$\sum B_{3j}\log\left(\frac{r}{w}\right)_{it-j} + \sum B_{4j}\log(Y)_{it-j}, \tag{11}$$

where i indexes industries. To exploit the panel nature of the data, equation (11) includes industry fixed effects, B_{0i}. The fixed effects can be interpreted as different industry technology efficiency parameters (a_{Ki}/a_{Li}) in a CES production function. B_{1i} refers to the industry-specific linear time trends that account for different rates of capital-biased technological change across industries.[23] The relative price of capital, r/w, is measured as the ratio of the user cost of capital to the wage rate. Note that the long-run elasticity of the capital-labour ratio with respect to the relative input price is computed as

---

empirical analysis that follows, demand conditions are accounted for and the relative price of capital is treated as an endogenous variable.

[23] Other methods of controlling for changes in the capital-labour ratio due to technological changes are explored in the appendix. The alternative methodologies do not change the main conclusions of this paper.

$\frac{\sum B_{3j}}{(1 - B_{21} - B_{22})}$. Also, we include the industry output (Y) to control for the potential scale effect. If the production technology is homothetic, the level of output should have no impact on the long-run capital-labour ratio. Thus, the long-run elasticity, $\frac{\sum B_{4j}}{(1 - B_{21} - B_{22})}$, is expected to be zero.

Equation (11) is estimated using the Arellano and Bond (1991) generalized method of moments (GMM) procedure.[24] The first difference of (11) is taken and estimated using GMM. Both lagged capital-labour ratios, the relative price of capital and industry output, are treated as endogenous. Lagged levels of the regressors are used as instruments.[25] Table 2 reports the results. Consistent with intuition, there exists a negative relationship between the capital-labour ratio and the relative price of capital. The point estimates of the long-run elasticities are somewhat sensitive to the different lag structures shown in columns (1) to (3) of Table 2. The long-run elasticity is -0.18 when j = 0, and it is -0.36 when j = 2. Our preferred specification refers to j = 0 because all estimates of the lagged relative price of capital are statistically insignificant in columns (2) and (3). Also, both Akaike and Schwartz selection criteria suggest that the model with j = 0 is preferred. The estimates in column (1) suggest that a 10 per cent increase in the relative price of capital leads to a 1.8 per cent decline in the capital-labour ratio in the long run.

Also consistent with intuition is the finding that industry output has no effect on the capital-labour ratio in the long run. Column (1) shows that the coefficient on contemporaneous industry output is negative, but once more lags are added in columns (2) and (3), the long-run elasticity becomes zero. The negative effect in the short run is to be expected, because adjustment costs associated with labour should be less than those for capital. A rise in industry output is achieved initially through the use of more labour.

---

[24] One-step GMM is used. Studies have shown that standard errors from the two-step GMM are downward biased; thus, Arellano and Bond (1991) recommend the use of one-step GMM for inference.

[25] For example, $\log(r/w)_{it-2}$ is used as an instrument for ?$\log(r/w)_{it}$. In fact, any lagged level, $\log(r/w)_{it-j}$, j = 2, is a valid instrument. The Arellano and Bond estimates presented in this paper use two lagged levels as instruments. The number of lags is restricted because introducing a large number of them leads to an "over-fitting" problem, where the Arellano-Bond estimates tend to move towards the estimates from the within-groups OLS estimator. See Leung and Yuen (2005) for more details.

Thus, the capital-labour ratio falls initially. After a period of time when capital also adjusts, the capital-labour ratio returns to its long-run value.

Each specification in Table 2 passes two specification tests. The Sargan test of overidentifying restrictions suggests that the moment restrictions are valid. Also, the hypothesis that there is no second-order serial correlation in the first-differenced residuals cannot be rejected.[26] The appropriateness of the Arellano-Bond estimator also depends on whether the instruments are weak. As Staiger and Stock (1997) suggest, GMM estimates can be subject to substantial bias if instruments are weak. Stock, Wright, and Yogo (2002) suggest a test of weak instruments whereby the instruments are regressed against the endogenous variable; they are classified as weak if the resulting *F*-statistic (from a test of joint significance) is lower than 10.[27] Based on this criterion, both the lagged capital-labour ratio and the lagged relative price of capital are not weak instruments. The regression of the ? $\log(K/L)_t$ on $\log(K/L)_{t-2}$ and $\log(K/L)_{t-3}$ yields an *F*-statistic of 35.5, and the regression of ? $\log(r/w)_t$ on $\log(r/w)_{t-2}$ and $\log(r/w)_{t-3}$ yields an *F*-statistic of 12.3.[28, 29]

As noted, in a CES framework, the long-run elasticity of the capital-labour ratio with respect to the relative input price in Table 2 suggests that the elasticity of substitution between labour and capital ranges from 0.18 to 0.36. A natural question is the extent to which these estimates are comparable to those in other studies. In Jorgenson's (1963) pioneering work on capital theory, the elasticity of substitution is assumed to be 1 in a Cobb-Douglas production function. Although recent empirical

---

[26] See Arellano and Bond (1991) for details on the Sargan test and the test for serial correlation.

[27] Although this test was suggested in the context of two-stage least squares, it should provide some indication of whether the instruments are weak in the GMM in a panel-data context.

[28] The system GMM estimator outlined in Blundell and Bond (1998) could have been used in place of the Arellano-Bond estimator if the instruments were found to be weak, but, given the size of the *F*-statistics in this case, it is not necessary. See the appendix for a full discussion of the Arellano-Bond and Blundell-Bond estimators.

[29] Given that panel unit root tests suggest the capital-labour ratio series cannot be distinguished from a non-stationary series, the validity of using lagged levels as instruments comes into question. These panel unit root tests, however, are known to lack power when the time-series element of the data is short, as is the case here. Potential problems can be avoided by using lagged differences as instruments, but the Arellano-Bond esimator with differenced instruments does not perform as well as the Arellano-Bond estimator with level instruments in small samples when the data are simply highly persistent. Table A-4 in the appendix compares estimates of long-run elasticities that use level instruments with those that use differenced instruments. Because we find that the estimates are similar, we provide in our main text only estimates that use level instruments.

studies find little support for the Cobb-Douglas assumption with estimates less than 1, Chirinko (2002) concludes that there is no consensus in the existing literature. For example, the implied elasticity in Caballero, Engel, and Haltiwanger (1995) is approximately 0.7. In contrast, Chirinko, Fazzari, and Meyer (1999) obtain a much smaller estimate of 0.25 using panel data of firm investment. Despite the wide variety of estimates, it is important to note that there is a potential downward bias due to the volatility of the data. If part of the variation in the relative input price is considered to be transitory rather than permanent, the estimated elasticity will be lower than that in the theoretical production function. The issue of volatility is discussed further in section 4.3.

4.2 The effect of the exchange rate

The exchange rate first affects the price of investment, which in turn affects the user cost and the capital-labour ratio. The degree to which the exchange rate affects the price of investment depends on the degree of pass-through into capital prices and the fraction of capital that is imported. Arguably, the exchange rate does directly affect the price of machinery and equipment, but not land and structures. Therefore, it is useful to first re-estimate (11) for M&E, other M&E, and ICT separately.

Table 3 shows the results of the preferred specifications of the regressions using the disaggregated capital-labour ratios.[30] The point estimates of the long-run effect of an increase in the relative price of capital for M&E (-0.33) and other M&E (-0.33) are both larger than the estimate for the total capital-labour ratio (-0.18) given in Table 2. On the other hand, the long-run effect on the ICT-labour ratio is zero. Since the relative quantity (price) of ICT is rising (falling) during the sample period, it is difficult to disentangle the effects of the relative price and the industry-specific trend.

All that is left to determine before the exchange rate's effect on the capital-labour ratio can be estimated is the exchange rate's effect on the user cost. Section 2.1 suggests that the user cost is approximately proportional to the price of investment. Therefore, a 1 per cent change in the price of investment leads to a 1 per cent change in the user cost. The price of investment itself is a weighted average of the imported and domestic price of

[30] The results for different lag lengths are shown in Tables A-1 to A-3 in the appendix.

capital, where the fraction of imported capital in total capital measured in current dollars is the weight. The imported share of machinery and equipment is usually derived from the input-output tables.[31] Using the input-output tables for commodities at the M-level, the average imported share of machinery and equipment is found to be 0.52.[32] Its evolution over time is shown in Figure 12. The share remained relatively stable at 0.5 until 1992. After 1992, the share increased continually, reaching two-thirds of total M&E expenditures in 1997.[33]

Assuming complete exchange rate pass-through into imported equipment prices,[34] the approximate effect of a permanent 10 per cent depreciation in the exchange rate is a 5.2 per cent increase in the price and user cost of M&E.[35] This implies a 1.7 (5.2 times -0.33) per cent decline in the M&E-labour ratio in the long run.[36] Given that capital compensation for M&E as a fraction of total capital compensation was 0.34 over the 1981–97 period, a 10 per cent depreciation in the exchange rate would lead to a

---

[31] The appendix provides a more detailed description of the process. The expenditure weights used in Statistics Canada's Machinery and Equipment Price Indexes (MEPI) cannot be used, because, even for the post-1986 period, expenditure weights for 1979–83 are used. See Statistics Canada (2003) for more detail.

[32] It would be preferable to perform the calculation at the more disaggregate L-level, but these data are not publicly available. Still, the approximation gives numbers similar to the ones calculated by Statistics Canada in the past. For example, Statistics Canada (1982) shows that the import expenditure weight in 1971 was 0.39, which is in line with the value of 0.41 computed using the M-level data. Furthermore, the weight derived from MEPI for the post-1986 period is 0.51. This is close to the value calculated using the M-level data for 1979 (0.49) and 1980 (0.48), but higher than the values in 1981 (0.43), 1982 (0.39), and 1983 (0.43).

[33] The imported share of machinery was not calculated for the years after 1997, because the input-output tables based on SIC end in 1997.

[34] There is no clear way of testing this assumption, because prices for imported M&E are generally U.S. producer prices from the Bureau of Labor Statistics adjusted for exchange rates, taxes, and custom tariffs. See Statistics Canada (2003) for more detail. These constructed imported M&E prices are used in Statistics Canada's calculation of the user cost of capital, which is subject to some error if pass-through is not complete. This measurement error may be another reason why the price of labour has a greater effect on the capital-labour ratio than the user cost of capital.

[35] A simple way to confirm whether the estimated imported share of M&E is appropriate is to regress the growth in the price of M&E on the growth of the exchange rate. This yields a point estimate of 0.52 with 95 per cent confidence interval bands at 0.45 and 0.60. Furthermore, a regression of the growth in the total price of capital on the growth of the exchange rate yields a point estimate of 0.23 with 95 per cent confidence bands at 0.14 and 0.32. The fraction of imported M&E (0.52) multiplied by the average share of M&E in capital (0.34), 0.18 is within the above confidence bands.

[36] The effect of the exchange rate on the M&E-labour ratio measured in this paper is due solely to the change in the relative price of capital. Industry output is being held constant. As in the case of the total capital-labour ratio, we find that the long-run effect of industry output on the M&E-labour ratio is zero.

0.59 (1.7 times 0.34) per cent decrease in the total capital-labour ratio. This estimated 0.59 decrease in the capital-labour ratio caused by a 10 per cent depreciation in the exchange rate is an upper bound, because complete pass-through is assumed. If any part of imported M&E is priced to market, this estimate should be lower.[37]

To better understand the magnitudes of the effects of the relative price of capital and the exchange rate on the capital-labour ratio, the estimated coefficients from Table 3 can be used to obtain predicted M&E-labour growth rates for each of the industries. However, it would not be clear how to aggregate these predicted industry-level growth rates into a growth rate for the manufacturing industry as a whole.[38] Instead, the aggregate values for the growth in the relative price of M&E are used to generate predicted aggregate growth in the M&E-labour ratio in the following way:

$$\Delta \log\left(\frac{\hat{K}}{L}\right)_t = \hat{B}_1 + \sum \hat{B}_{2j} \Delta \log\left(\frac{\hat{K}}{L}\right)_{t-j} + \sum \hat{B}_{3j} \Delta \log\left(\frac{r}{w}\right)_{t-j} \qquad \text{if } t = 1983,$$

where $\hat{B}_1$ is the average coefficient for the industry-specific time trend.[39] The predicted M&E-labour growth rates are then used to generate indexes. To assess the impact of the exchange rate, changes in the relative price of M&E net of exchange rate changes are defined as:

$$\Delta \log\left(\frac{r}{w}\right)_t - 0.52 * \Delta \log(er)_t,$$

---

[37] The Canada-U.S. exchange rate can be entered into (14) to obtain a direct estimate of the effect of the exchange rate on the M&E-labour ratio. When the exchange rate is entered directly into the regression, the long-run elasticity of the relative price of M&E becomes -0.26, lower than the value reported in Table 3. The long-run elasticity of the exchange rate is -0.24, but statistically insignificant. The statistical insignificance is not surprising, because Figure 6 shows that the exchange rate and the relative price of M&E are highly correlated. Furthermore, the coefficient on the exchange rate is difficult to interpret, because there is a direct mechanical link between the exchange rate, the price of imported M&E, and the user cost of M&E. The user cost cannot be held constant when the exchange rate changes. See the appendix for more details.

[38] Growth in labour input can be aggregated using the nominal cost of labour, and growth in capital services can be aggregated using the nominal cost of capital, but it is unclear how to aggregate growth in the capital-labour ratio.

[39] The predicted logged differences of the M&E-labour ratio cannot be obtained in 1981 and 1982. Therefore, the actual logged differences are used in their place.

where *er* is the Canada-U.S. exchange rate. These net relative price changes can then be used to compute predicted M&E-labour growth rates net of exchange rate changes. Figure 13 shows the actual M&E-labour ratio, the M&E-labour ratio implied by the evolution of the relative price of M&E, and the M&E-labour ratio implied by the changes in the relative price of M&E net of exchange rate effects. Growth in the predicted M&E-labour was negligible during the 1983–87 period because the relative price was rising at that time. The subsequent decline in the relative price of M&E generated a sharp upward movement in the predicted M&E-labour ratio, but not as sharp as the actual ratio. The rise in the relative price of M&E in 1991 slowed the growth of the predicted M&E-labour until after 1995, when the relative price fell once again.

Figure 13 also shows that the effects of the exchange rate are not large. If the exchange rate did not depreciate in the early 1980s, the predicted M&E ratio would have been slightly higher. However, the appreciation in the late 1980s eliminated this gap between the predicted M&E ratio and the predicted M&E ratio net of exchange rate effects. The depreciation in the 1990s leads to lower levels of M&E-labour, but again the exchange rate effect does not appear to be large.

To better quantify the effects, Table 4 gives the average annual growth rates for the actual M&E ratio, the predicted M&E ratio, and the predicted M&E ratio net of exchange rate effects. If the exchange rate did not change during the 1983–87 period, it would have added only 0.2 percentage points to the average annual M&E-labour growth rate over that period. Similarly, if the exchange rate did not depreciate in the post-1991 period, it would have added 0.3 percentage points to the average annual M&E-labour growth rate between 1992 and 1997. Translated into cumulative growth terms, the model predicts that M&E-labour rises by 12.4 per cent between 1991 and 1997. Net of exchange rate effects, the model predicts that M&E-labour rises by 14.7 per cent, 2.3 percentage points higher. This may appear to be significant, but considering that both M&E as a share of total capital and capital's share of nominal output are roughly one-third, the effect on labour productivity, calculated using a simple growth accounting framework, is small.[40]

4.3 Sensitivity analysis

One issue worth exploring is whether the estimated elasticities are stable over time. A notable change in Canadian manufacturing is that its export orientation rose rapidly after the implementation of the North American Free Trade Agreement (NAFTA) in 1989. Changes in production technology due to NAFTA might have had an impact on the elasticity of substitution between capital and labour. This, in turn, would affect the sensitivity of the capital-labour ratio to relative input price. To check whether this is the case, some of Table 3 is replicated for the 1981–89 and 1990–97 periods. The results are reported in Table 5. The point estimates of the long-run price elasticities are 0.29 and 0.30 for the 1981–89 and 1990–97 periods, respectively. The 95 per cent confidence intervals around the estimates for the earlier period encompass the point estimates of the latter period, so the difference is not statistically significant. These results suggest that movements in the relative input price have the same impact on the capital-labour ratio before and after 1990. The timing of the effect of the relative price, however, does differ between the two periods. In the 1981–89 period, the lag of the relative price is significant, but the relative price is not. In the 1990–97 period, the lag of the relative price is not significant, but the relative price is.

Another issue is that the user cost effect is restricted to having the same magnitude as the effect of the price of labour in equation (11). This is consistent with the theory that the long-run capital-labour ratio is determined by the relative price of inputs. Therefore, the long-run effect of a 1 per cent increase in the user cost on the capital-labour ratio should be identical to a 1 per cent decline in wages. There are reasons to believe that the capital-labour ratio may react more to changes in the price of labour than to changes in the price of capital.

---

[40] Since M&E is only one-third of total capital, the total *K/L* ratio would be only 1.5 percentage points higher in 1997. Furthermore, given that capital's share of nominal GDP is one-third, a simple growth accounting framework would suggest that labour productivity would be only 0.5 percentage points higher.

First, firms may consider much of the variation in the user cost to be transitory shocks.[41] Kiyotaki and West (1996) argue that this is the main reason why they find a much larger elasticity of capital with respect to output than with respect to the user cost. If the adjustment cost of labour is lower than that of capital, transitory shocks are likely to induce changes in labour input, and to a lesser extent changes in capital. This would have a negative impact on the capital-labour ratio in the short run, but not in the long run.

Second, fluctuations in wages are normally less volatile than the user cost.[42] As noted in the theoretical model, the adjustment paths of capital and labour depend on the gap between the current level and the long-run equilibrium, $\tilde{K}$ and $\tilde{L}$. Firms have to infer the impact on $\tilde{K}$ and $\tilde{L}$ from changes in input prices. They adjust their quasi-fixed inputs only if input price movements are persistent. Therefore, it is critical for firms to distinguish between permanent and transitory shocks. When input prices are volatile, the nature of the shocks is more difficult to determine. As a result, uncertainty tends to weaken input adjustments to price movements. As input prices become more volatile, quasi-fixed inputs become less responsive.

To test whether the capital-labour ratio is more sensitive to changes in the price of labour than the user cost, we re-estimate equation (11) for M&E by separating the relative price of M&E into r and w. That is,

$$\log\left(\frac{K}{L}\right)_{it} = B_{0i} + B_{1i}t + B_{21}\log\left(\frac{K}{L}\right)_{it-1} + B_{22}\log\left(\frac{K}{L}\right)_{it-2} + B_3\log Y_{it} + B_4\log r_{it} + B_5\log w_{it}\,. \tag{12}$$

[41] A formal way to test this hypothesis is to decompose the user cost into permanent and transitory components using some statistical procedure, such as the Beveridge-Nelson decomposition. In theory, higher estimates of the long-run elasticity would be expected if the observed user cost were replaced by its permanent component. Since only 17 years of annual data are available, such decomposition may not be reliable.

[42] The mean of the coefficient of variation across industries is 0.18 for wages and 0.38 for the user cost of capital over the sample period.

Equation (12) is estimated following the Arellano and Bond (1991) procedure.[43] Table 6 reports the results. The M&E-labour ratio is more sensitive in the long run to changes in the price of labour than the user cost of M&E. The estimate of the long-run effect of the price of labour (0.84) is larger in absolute value than that of the user cost (-0.29).

5. Concluding Remarks

We have examined the long-run impact of exchange rate changes on the capital-labour ratio in the Canadian manufacturing sector. First, a dynamic factor demand framework with multiple quasi-fixed factors was adopted to test whether the capital-labour ratio responds to movements in the relative input price. Consistent with the theory, there exists a negative relationship between the capital-labour ratio and the user cost-wage ratio. Our estimate of the long-run elasticity for the M&E-labour ratio is about -0.33. Furthermore, the substitution between labour and capital is much stronger in response to changes in the wage rate than the user cost of capital. This result highlights the potential role of price volatility in determining the quasi-fixed inputs. Movements in wages have followed a stable pattern in most industries, and therefore they are likely to be considered permanent shocks to the long-run equilibrium level of the capital-labour ratio. This translates to adjustments in capital and labour. On the other hand, the user cost of capital is much more volatile. If the fluctuations are mainly transitory, they would be sheltered by changes in the variable, but not quasi-fixed inputs.

We have argued that exchange rates had a limited role in the evolution of the capital-labour ratio in Canada during the 1981–97 period. Even if complete exchange rate pass-through into imported M&E prices is assumed, the effect of the exchange rate on the user cost of capital is small, because imported M&E investment is only one-half of total M&E investment, and M&E is approximately only one-third of total capital. As a result, even a 10 per cent depreciation in the exchange rate causes only a 5.2 per cent decline in

[43] All the regressors are treated as endogenous. As in the previous regressions, the Sargan test suggests that the moment restrictions are valid, no second-order serial correlation in the error term is found, and the instruments are sufficiently correlated to the regressors. Auxiliary regressions of the regressors on two

the user cost of M&E. Combined with a long-run relative price elasticity of -0.33, this implies a 1.7 per cent and 0.6 per cent decline in the M&E-labour ratio and the total capital-labour ratio, respectively. The evolution of the capital-labour ratio is driven by changes in the relative price of capital that are not linked to exchange rate fluctuations.

In this paper, the estimated effect of the exchange rate on the capital-labour ratio is through the user cost channel. One might argue that the effect on the capital-labour ratio depends on which component of the user cost is changing. Schaller (2002) finds that the effect on capital varies substantially across its components. The total capital stock is affected by its own price, but the long-run elasticity with respect to the real interest rate and taxes is close to zero. For future research, it would be interesting to explore how the capital-labour ratio responds to different components of the user cost.

---

lagged levels yield F-statistics of 11.29, 26.64, and 29.16 for the user cost of capital, price of labour, and price of output, respectively.

References

Alonso-Borrego, C. and M. Arellano. 1999. "Symmetrically Normalized Instrumental-Variable Estimation Using Panel Data." *Journal of Business and Economic Statistics* 17(1): 36–49.

Arellano, M. and S. Bond. 1991. "Some Tests of Specification of Panel Data: Monte Carlo Evidence and an Application to Employment Equations." *Review of Economic Studies* 58(2): 277–97.

Blundell, R. and S. Bond. 1998. "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models." *Journal of Econometrics* 87(1): 115–43.

Brynjolfsson, E. and L.M. Hitt. 2000. "Beyond Computation: Information Technology, Organizational Transformation and Business Performance." *Journal of Economic Perspectives* 14(4): 23–49.

Caballero, R.J., E. Engel, and J.C. Haltiwanger. 1995. "Plant-Level Adjustment and Aggregate Investment Dynamics." *Brookings Papers on Economic Activity* 2(1995): 1–54.

Campa, J. and L.S. Goldberg. 1995. "Investment in Manufacturing, Exchange Rates and External Exposure." *Journal of International Economics* 38(2): 297–320.

_________. 1999. "Investment, Pass-Through and Exchange Rates: A Cross-Country Comparison." *International Economic Review* 40(2): 287–314.

_________. 2001. "Employment versus Wage Adjustment and the U.S. Dollar." *Review of Economics and Statistics* 83(3): 477–89.

Chirinko, R.S. 2002. "Corporate Taxation, Capital Formation, and the Substitution Elasticity between Labor and Capital" *National Tax Journal* 55(2): 339–55.

Chirinko, R.S., S.M. Fazzari, and A.P. Meyer. 1999. "How Responsive is Business Capital Formation to Its User Cost?: An Exploration with Micro Data." *Journal of Public Economics* 74(1): 53–80.

Christensen, L.R. and D.W. Jorgenson. 1969. "The Measurement of U.S. Real Capital Input, 1929–1967." *Review of Income and Wealth* 15(4): 293–320.

Dekle, R. 1998. "The Yen and Japanese Manufacturing Employment." *Journal of International Money and Finance* 17(5): 785–801.

Dupuis, D. and D. Tessier. 2000. "Une analyse empirique du lien entre la productivité et le taux de change réel Canada-É-U." Bank of Canada Working Paper No. 2000-22.

Gu, W., M. Kaci, J.-P. Maynard, and M.-A. Sillamaa. 2002. "The Changing Composition of the Canadian Workforce and Its Impact on Productivity Growth." In *Productivity Growth in Canada – 2002*, edited by J.R. Baldwin and T.M. Harchaoui, 67–100. Statistics Canada, Catalogue 15-204.

Hadri, K. 2000. "Testing for Stationarity in Heterogeneous Panel Data." *Econometrics Journal* 3(2): 148–61.

Hamermesh, D.S. and G.A. Pfann. 1996. "Adjustment Costs in Factor Demand." *Journal of Economic Literature* 34(3): 1264–92.

Harchaoui, T.M. and R. Tarkhani. 2002. "A Comprehensive Revision of the Capital Input Methodology for Statistics Canada's Multifactor Productivity Program." In *Productivity Growth in Canada – 2002*, edited by J.R. Baldwin and T.M. Harchaoui. Statistics Canada, Catalogue 15-204: 101–58.

Harchaoui, T.M., R. Tarkhani, and T. Yuen. 2003. "Investment and Exchange Rate in Canadian Manufacturing." Statistics Canada, Preliminary.

Im, K., M. Pesaran, and Y. Shin. 1997. "Testing for Unit Roots in Heterogeneous Panels." Department of Applied Economics, University of Cambridge, Working Paper No. 9526.

Jorgenson, D.W. 1963. "Capital Theory and Investment Behavior." *American Economic Review* 53(2): 247–59.

Judson, A.R. and A.L. Owen. 1999. "Estimating Dynamic Panel Data Models: A Guide for Macroeconomists." *Economic Letters* 65(1): 9–15.

Kiyotaki, N. and K.D. West. 1996. "Business Fixed Investment and the Recent Business Cycle in Japan." *Macroeconomics Annual* 11: 277–323.

Lafrance, R. and L. Schembri. 1999–2000. "The Exchange Rate, Productivity, and Standard of Living." *Bank of Canada Review* (Winter): 17–28.

Leung, D. and T. Yuen. 2005. "Labour Market Adjustments to Exchange Rate Fluctuations: Evidence from Canadian Manufacturing Industries." Bank of Canada Working Paper. Forthcoming.

MacCallum, J. 1999. "Seven Issues in the Choice of Exchange of Regime for Canada." *Current Analysis*: Royal Bank of Canada, February.

Nickell, S. 1981. "Biases in Dynamic Models with Fixed Effects." *Econometrica* 49(6): 1417–26.

———. 1984. "An Investigation of the Determinants of Manufacturing Employment in the United Kingdom." *Review of Economic Studies* 51(4): 529–57.

———. 1986. "Dynamic Models of Labour Demand." In *Handbook of Labor Economics, Vol. 1*, edited by O. Ashenfelter and R. Layard, 473–522. North Holland: Elsevier Science Publishers.

Nordhaus, W.D. 2002. "Productivity Growth and the New Economy." *Brookings Papers on Economic Activity* 2002(2): 211–44.

Oliner, S.D. and D.E. Sichel. 2000. "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives* 14(4): 3–22.

Ouellette, P. and S. Vigeant. 2003. "Technological Choices and Regulation: The Case of the Canadian Manufacturing Sectors." *Canadian Journal of Economics* 36(2): 88–125.

Parham, D. 2002. "Productivity and Policy Reform in Australia." *International Productivity Monitor* 2002(5): 53–63.

Rao, S., J. Tang, and W. Wang. 2003. "Canada's Recent Productivity Record and Capital Accumulation." *International Productivity Monitor* 7 (Fall): 24–38.

Sargent, T.J. 1978. "Estimation of Dynamic Labor Demand Schedules under Rational Expectations." *Journal of Political Economy* 86(6): 1009–44.

Schaller, H. 2002. "Estimating the Long-Run User Cost Elasticity." MIT Working Paper No. 02-31.

Staiger, D. and J. Stock. 1997. "Instrumental Variables Regressions with Weak Instruments." *Econometrica* 65(3): 557–86.

Statistics Canada. 1982. *Machinery and Equipment Price Indexes by Industry of Purchase*. Catalogue 62-552 Occasional.

Statistics Canada. 2003. *Capital Expenditure Price Statistics*. Catalogue 62-007-XPB.

Stiroh, K.J. 2001. “Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?” Federal Reserve Bank of New York. Manuscript.

Stock, J., J. Wright, and M. Yogo. 2002. “A Survey of Weak Instruments and Weak Identification in Generalized Methods of Moments.” *Journal of Business and Economic Statistics* 20(4): 518–29.

Table 1. Capital-Labour Ratios in 21 Manufacturing Industries 1981–97

	K/*L* avg. annual growth rates	*r*/*w* avg. annual growth rates
Fabricated metal products	-0.0117	0.0210
Non-metallic mineral products	-0.0083	0.0259
Chemical and chemical products	-0.0051	0.0427
Machinery (except electrical)	-0.0029	0.0215
Furniture and fixture	-0.0023	0.0366
Beverage	0.0023	0.0546
Food	0.0029	0.0284
Plastic products	0.0050	0.0134
Tobacco products	0.0061	0.0788
Textile products	0.0062	-0.0137
Wood	0.0064	0.0513
Printing and publishing	0.0114	-0.0027
Other manufacturing	0.0161	0.182
Primary textile	0.0177	0.0260
Transportation equipment	0.0184	0.0020
Rubber products	0.0210	0.0907
Primary metal	0.0233	0.0180
Paper and allied products	0.0235	0.0125
Clothing	0.0251	0.0150
Electrical and electronic products	0.0309	-0.0025
Leather products	0.0332	-0.0429

Table 2. The Effect of the Relative Price of Capital on *K*/*L*, 1981–97

	(1) $j = 0$	(2) $j = 1$	(3) $j = 2$
$\log(K/L)_{t-1}$	0.7424	0.8488	0.8427
	(0.0840)	(0.0860)	(0.0948)
$\log(K/L)_{t-2}$	-0.2842	-0.1796	-0.2580
	(0.0752)	(0.0568)	(0.0812)
$\log(r/w)_{t}$	-0.0948	-0.1121	-0.1331
	(0.0214)	(0.0365)	(0.0261)
$\log(r/w)_{t-1}$		0.0463	-0.0188
		(0.0562)	(0.0727)
$\log(r/w)_{t-2}$			0.0023
			(0.0338)
$\frac{\sum \log(r/w)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.1750	-0.1989	-0.3602
	(0.0337)	(0.1092)	(0.1446)
$\log Y_{t}$	-0.0814	-0.1760	-0.1357
	(0.0375)	(0.0689)	(0.0869)
$\log Y_{t-1}$		0.2323	0.4091
		(0.1085)	(0.1582)
$\log Y_{t-2}$			-0.1725
			(0.0982)
$\frac{\sum \log Y_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.1501	0.1703	0.2431
	(0.0716)	(0.2161)	(0.3426)
Akaike	-5.3114	-5.2166	-5.1820
Schwartz	-4.9982	-4.8783	-4.8187

Notes: Arellano and Bond (1991) GMM estimates are presented. Robust standard errors are in parentheses. All regressions include industry fixed effects and industry-specific time trends.

Table 3. The Effect of the Relative Price of Capital on *K/L* by Type of Capital

	M&E (1)	Other M&E (2)	ICT (3)
$\log(K/L)_{t-1}$	0.7044	0.8605	0.6794
	(0.1023)	(0.0869)	(0.1066)
$\log(K/L)_{t-2}$	-0.3313	-0.3941	0.0042
	(0.0701)	(0.0708)	(0.0848)
$\log(r/w)_t$	-0.2089	-0.1743	0.0047
	(0.0557)	(0.0505)	(0.1114)
$\log(r/w)_{t-1}$			0.0762
			(0.0490)
$\dfrac{\sum \log(r/w)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.3333	-0.3266	0.2557
	(0.0852)	(0.0910)	(0.3260)

Notes: The dependent variables in columns (1) to (3) are the capital-labour ratios for M&E, other M&E, and ICT. The independent variables are lagged dependent variables, lags of the corresponding relative price of capital, and lags of industry output. All regressions include industry-specific effects and industry-specific time trends. Robust standard errors are in parentheses.

Table 4. Annual Average Growth Rates of M&E-Labour Ratio (%)

	Actual	Predicted	Predicted net of exchange rate effects
1983–87	1.4	0.3	0.5
1988–91	7.9	7.4	7.0
1992–97	0.6	2.0	2.3

Table 5. The Effect of the Relative Price of M&E on the M&E-Labour Ratio, 1981–89, 1990–97

	(1)	(2)	(3)	(4)
	1981–89		1990–97	
	$j = 0$	$j = 1$	$j = 0$	$j = 1$
$\log(K/L)_{t-1}$	0.5570 (0.1101)	0.4950 (0.1348)	0.6381 (0.0705)	0.6546 (0.0809)
$\log(K/L)_{t-2}$	-0.1041 (0.1029)	-0.1772 (0.0999)	-0.2888 (0.0636)	-0.2932 (0.0629)
$\log(r/w)_{t}$	-0.0426 (0.1029)	-0.0028 (0.1006)	-0.1998 (0.0558)	-0.2450 (0.0797)
$\log(r/w)_{t-1}$		-0.1938 (0.0540)		0.0735 (0.0778)
$\frac{\sum \log(r/w)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.0779 (0.1803)	-0.2882 (0.2038)	-0.3070 (0.0864)	-0.2685 (0.1100)
$\frac{\sum \log(Y)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.6999 (0.5307)	-0.2880 (0.3770)	0.2608 (0.2083)	0.1221 (0.2078)
Akaike	-3.6521	-3.6863	-4.0374	-3.8992
Schwartz	-3.1794	-3.2136	-3.6469	-3.5087

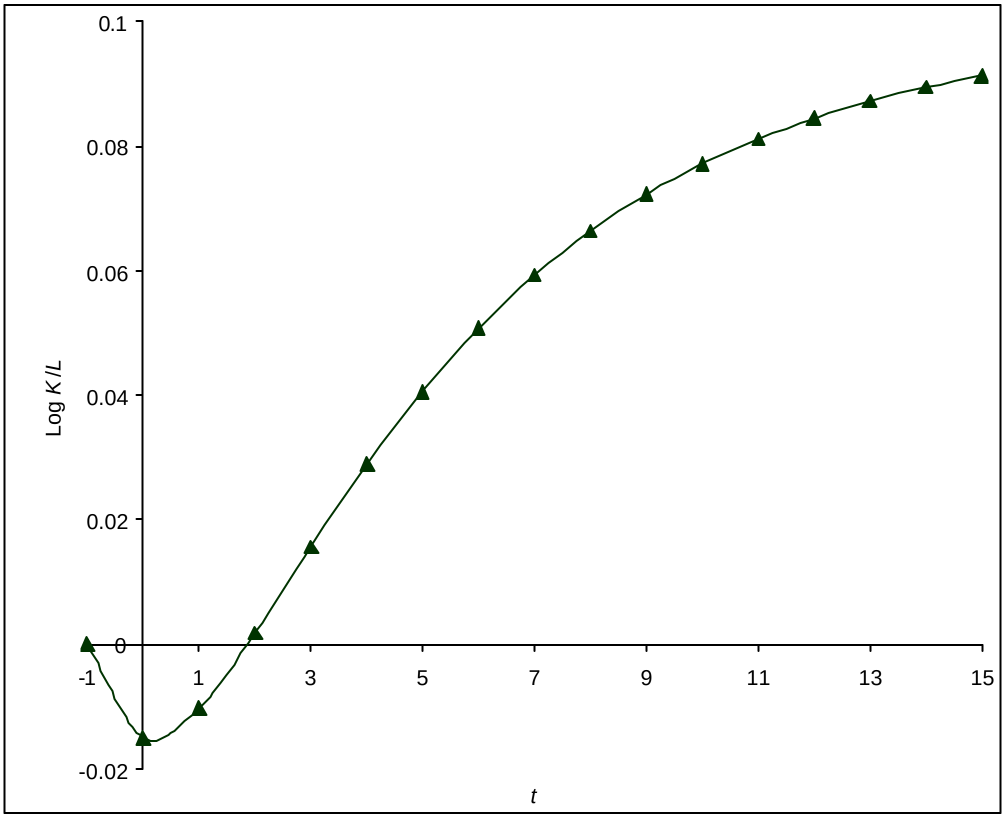
Notes: Arellano and Bond (1991) GMM estimates are presented. Robust standard errors are in parentheses. All regressions include industry fixed effects and industry-specific time trends.

Table 6. The Effect of the User Cost on the M&E-Labour Ratio

$(K/L)_{t-1}$	0.7916
	(0.0944)
$(K/L)_{t-2}$	-0.3520
	(0.0689)
r_t	-0.1612
	(0.0439)
$\dfrac{\sum \log r_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.2877
	(0.0708)
w_t	0.4704
	(0.2067)
$\dfrac{\sum \log w_{t-j}}{1-\sum \log(K/L)_{t-j}}$	0.8395
	(0.3754)
Akaike	-4.6232
Schwartz	-4.3601

Note: Robust standard errors are in parentheses.

Figure 1. Adjustment Path of a 10 Per Cent Increase in *K*/*L* to the Long-Run Equilibrium



Note: log K_{t-1} = 1, log L_{t-1} = 1, log $(K/L)_{t-1}$ = 0, log $\tilde{L}$ = 1.1, log $\tilde{K}$ = 1.2, log $\tilde{K}/\tilde{L}$ = 0.1.

Figure 2. Capital-Labour Quantity and Price Ratio (Index 1981 = 1)

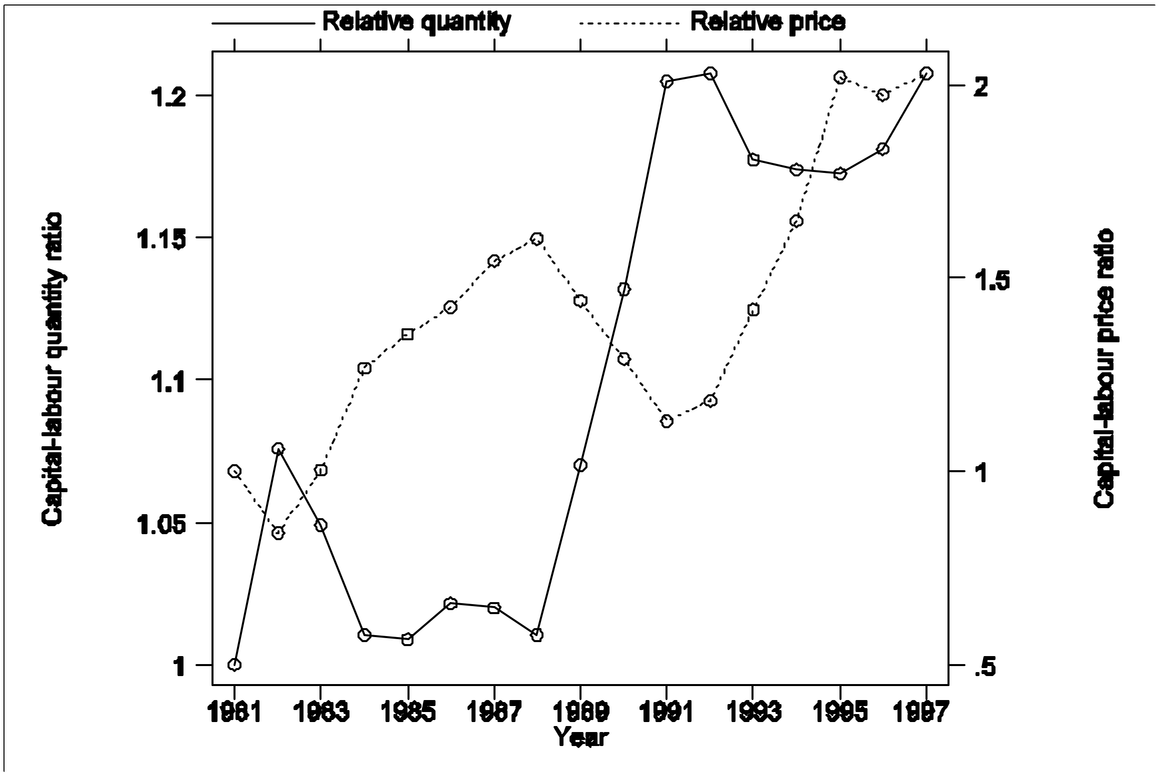


Figure 3. M&E-Labour Quantity and Price Ratio (Index 1981 = 1)

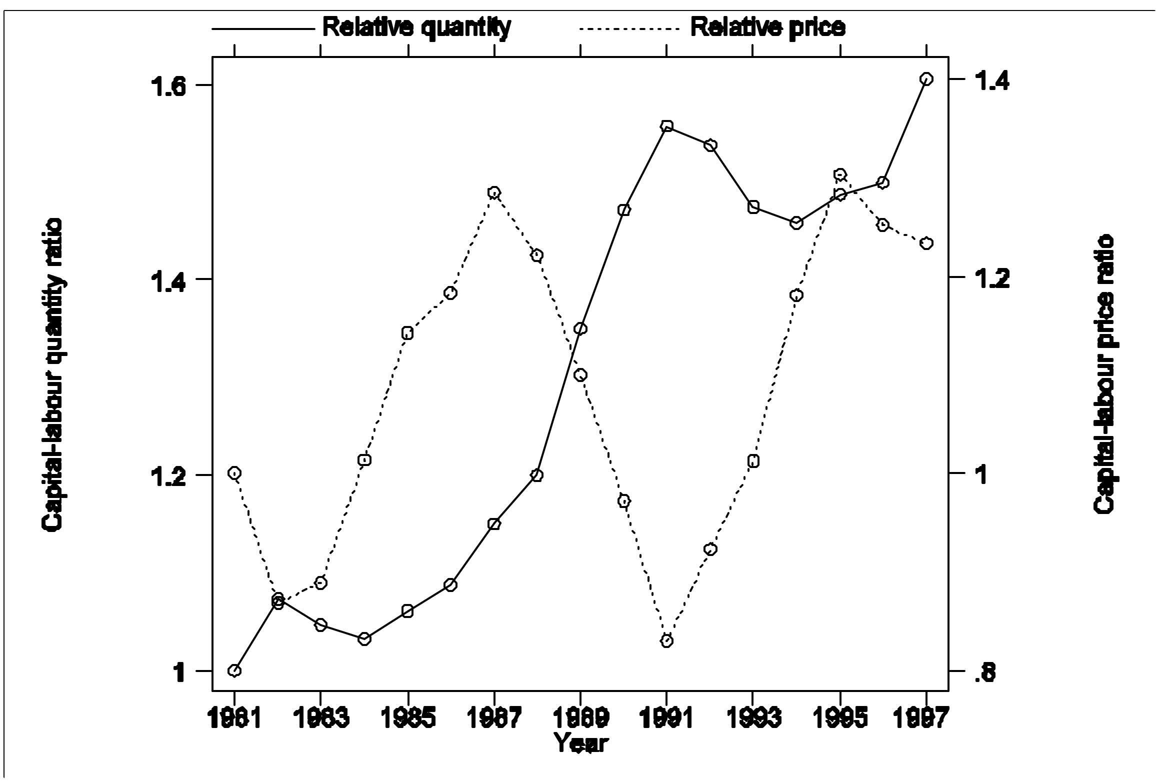


Figure 4. ICT-Labour Quantity and Price Ratio (Index 1981 = 1)

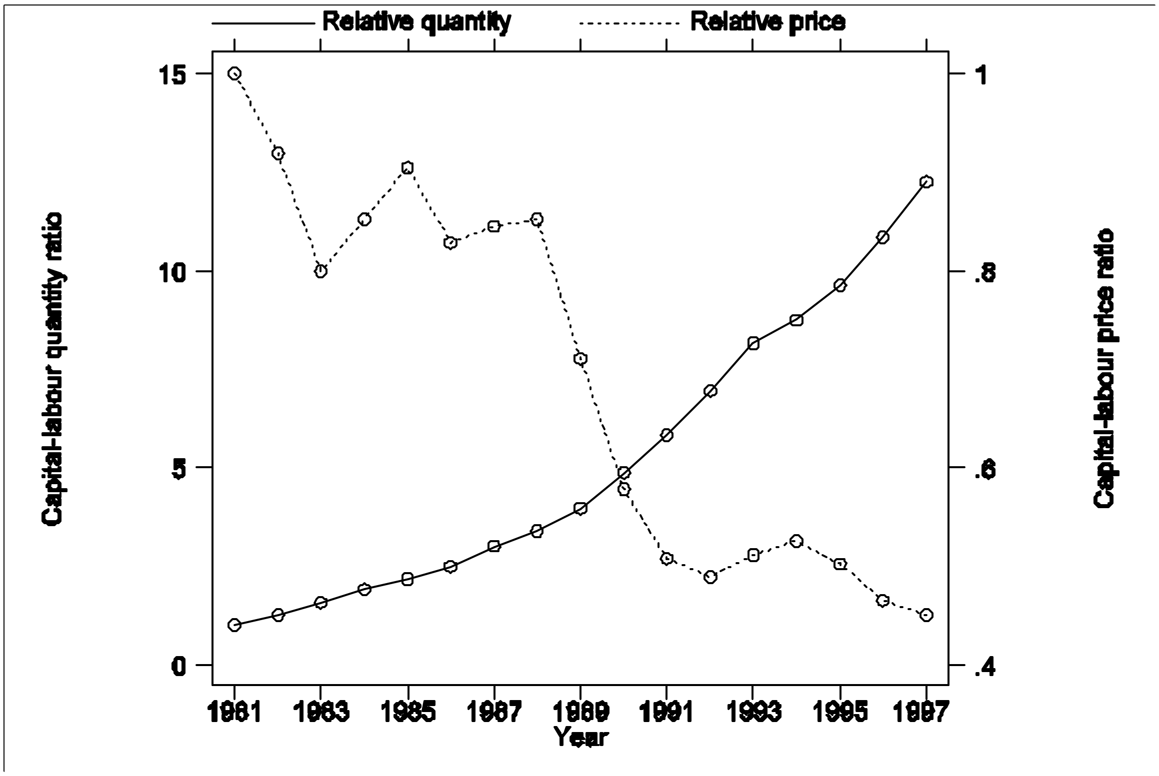


Figure 5. Other M&E-Labour Quantity and Price Ratio (Index 1981 = 1)

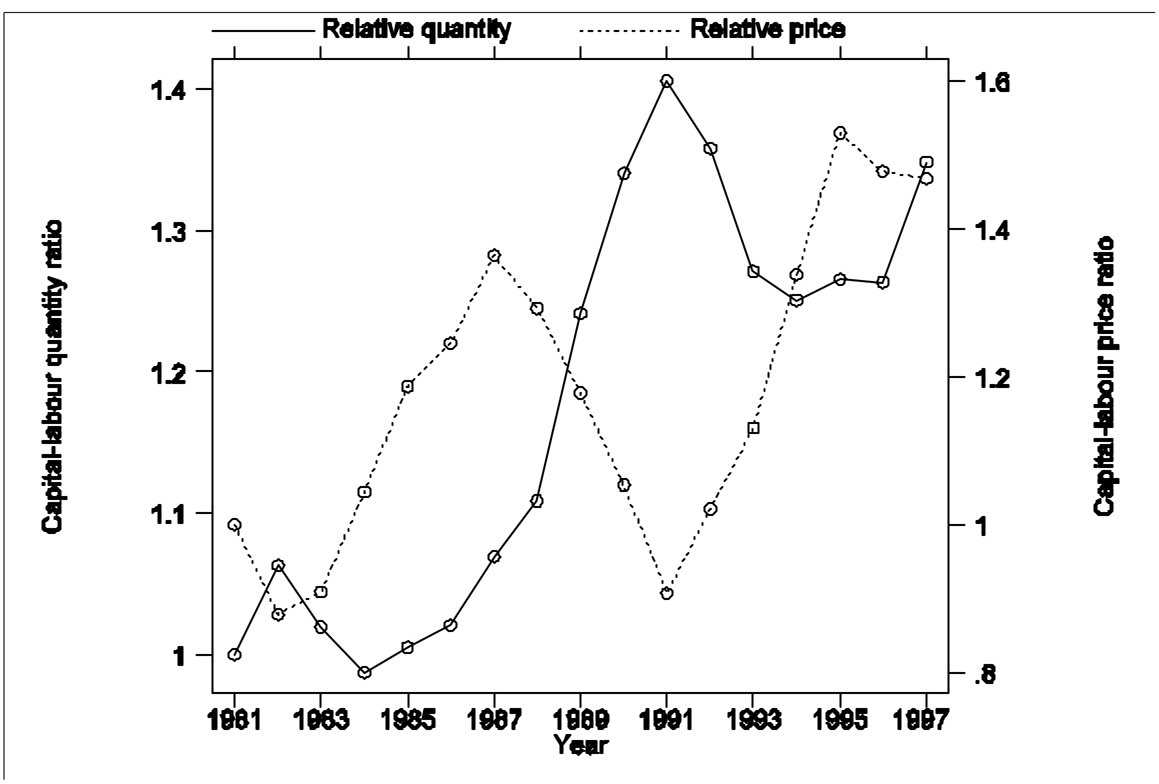


Figure 6. Canada-U.S. Exchange Rate and Relative Price of Capital (Index 1981 = 1)

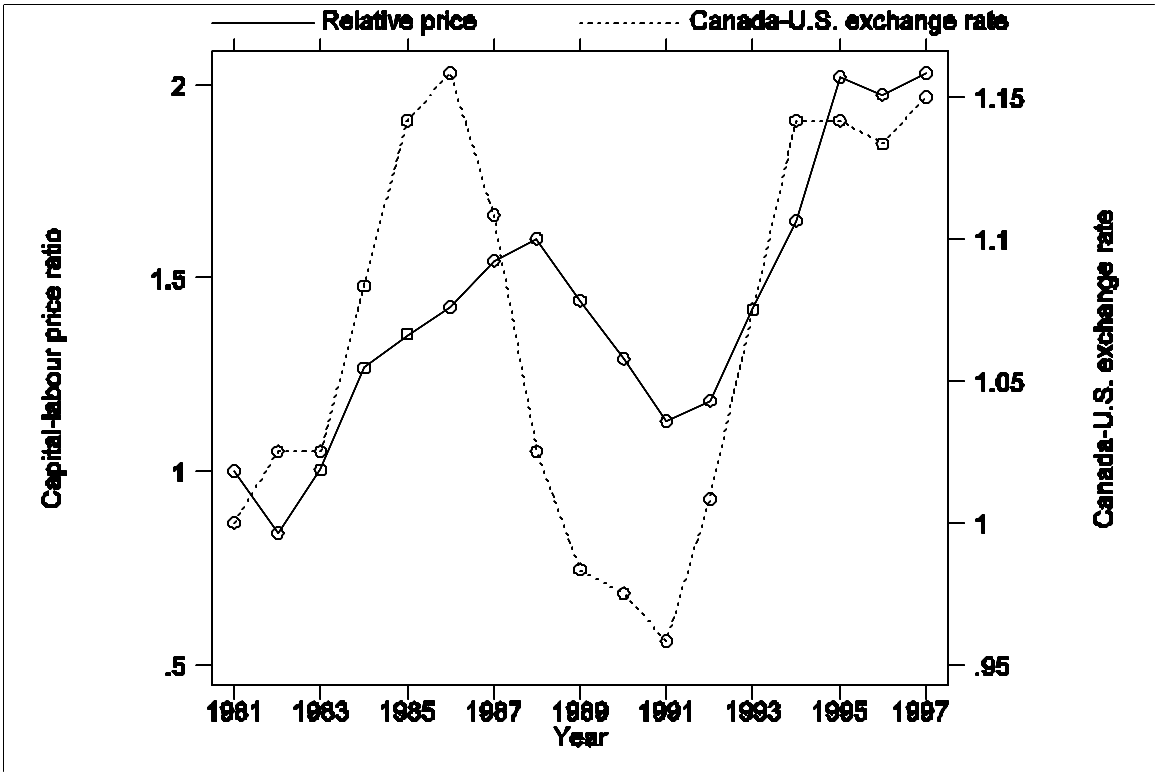


Figure 7. Canada-U.S. Exchange Rate and Relative Price of M&E (Index 1981 = 1)

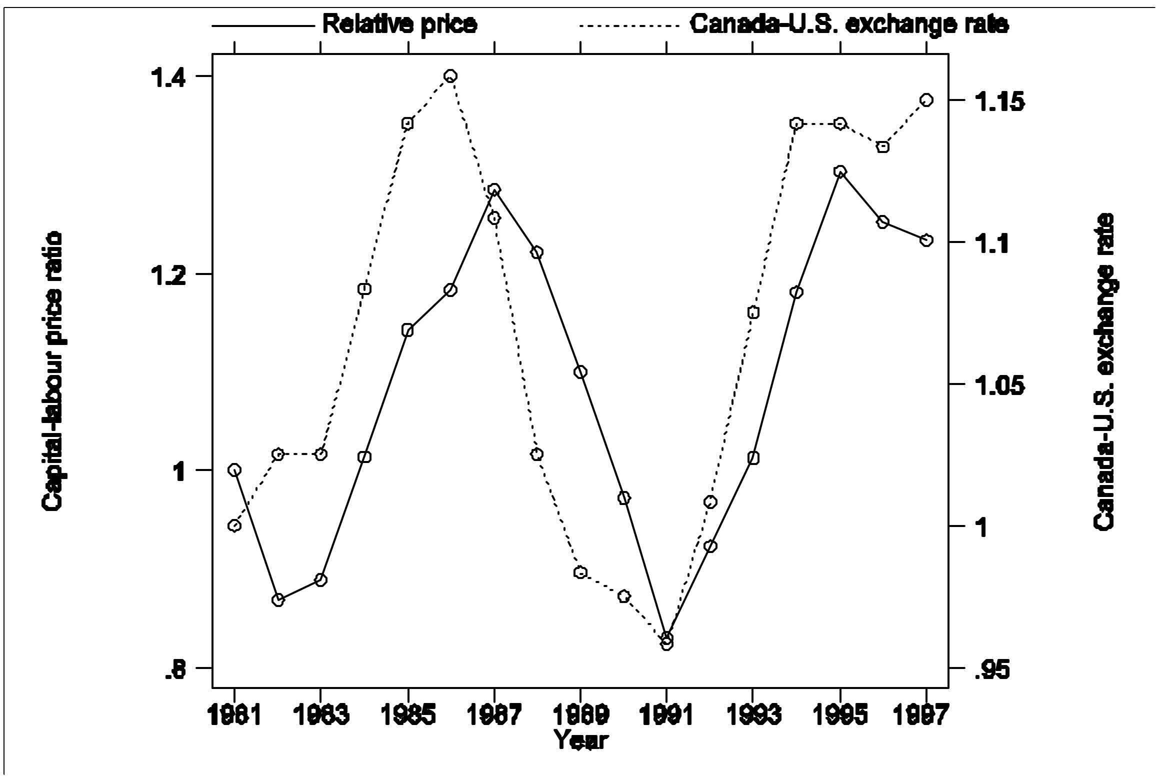


Figure 8. Canada-U.S. Exchange Rate and Relative Price of Other M&E (Index 1981 = 1)

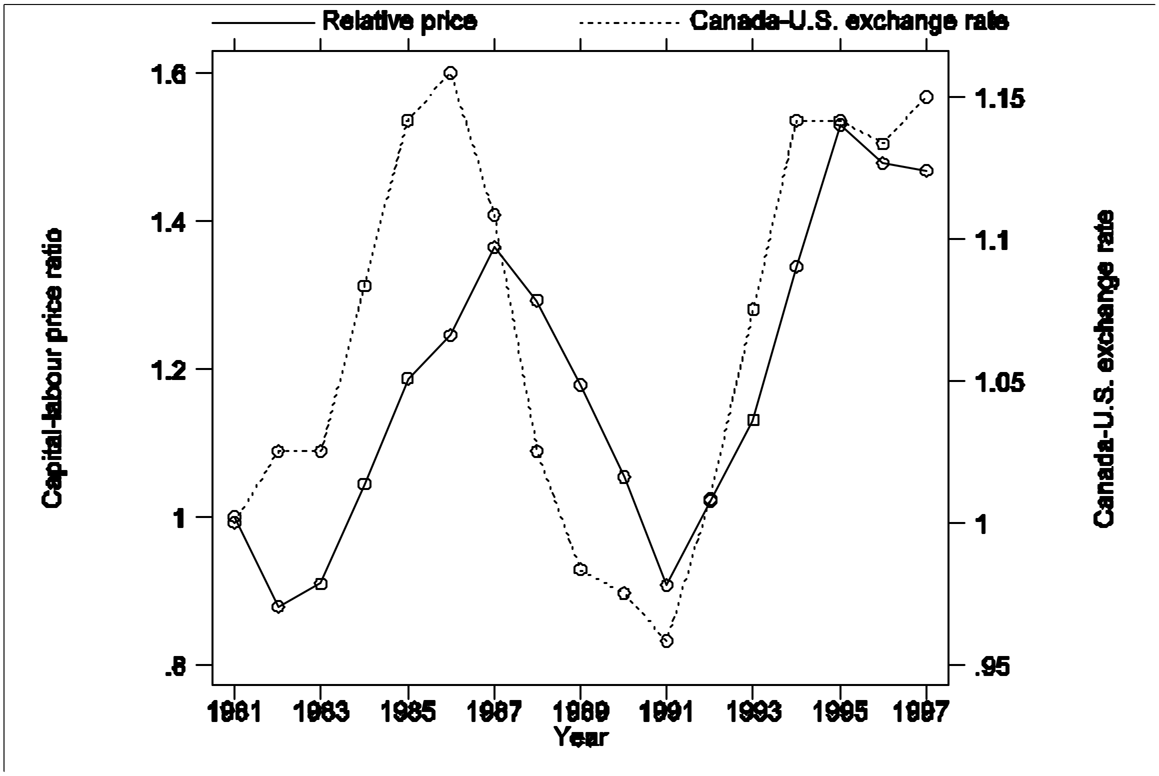


Figure 9. Canada-U.S. Exchange Rate and Relative Price of ICT (Index 1981 = 1)

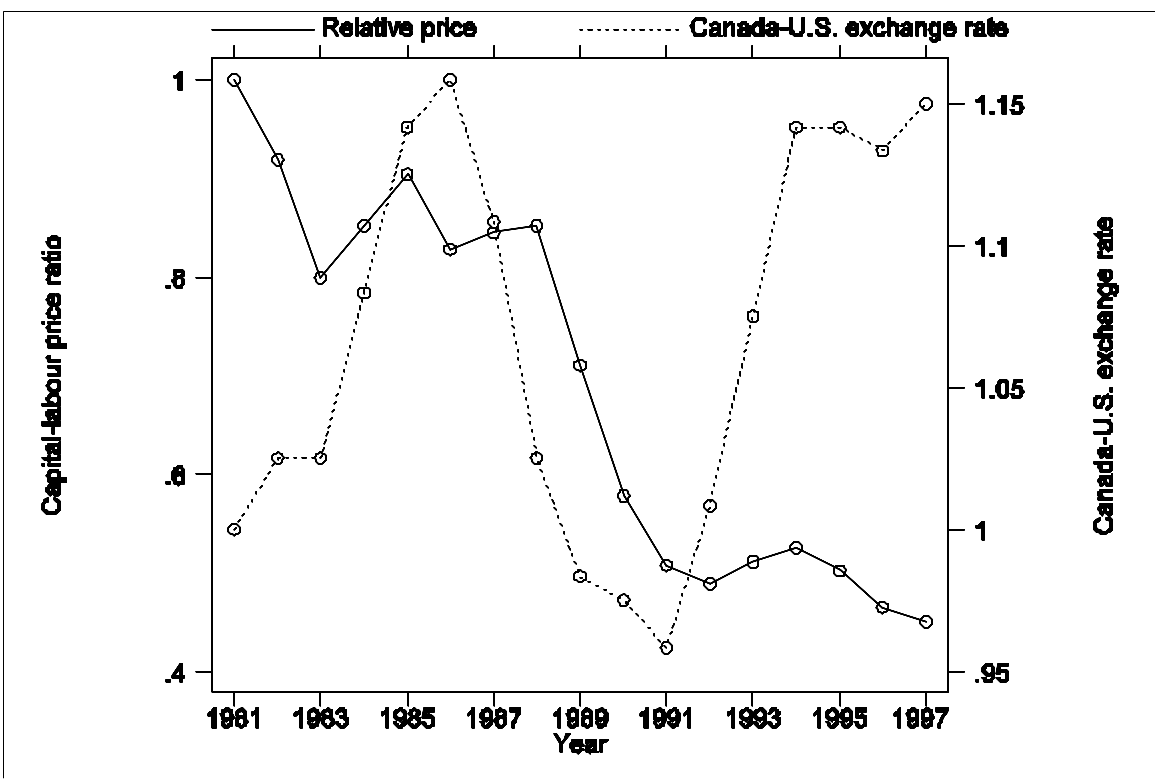


Figure 10. Capital-Labour Ratio in Logs by Industries, 1981–97 (Index 1981 = 0)

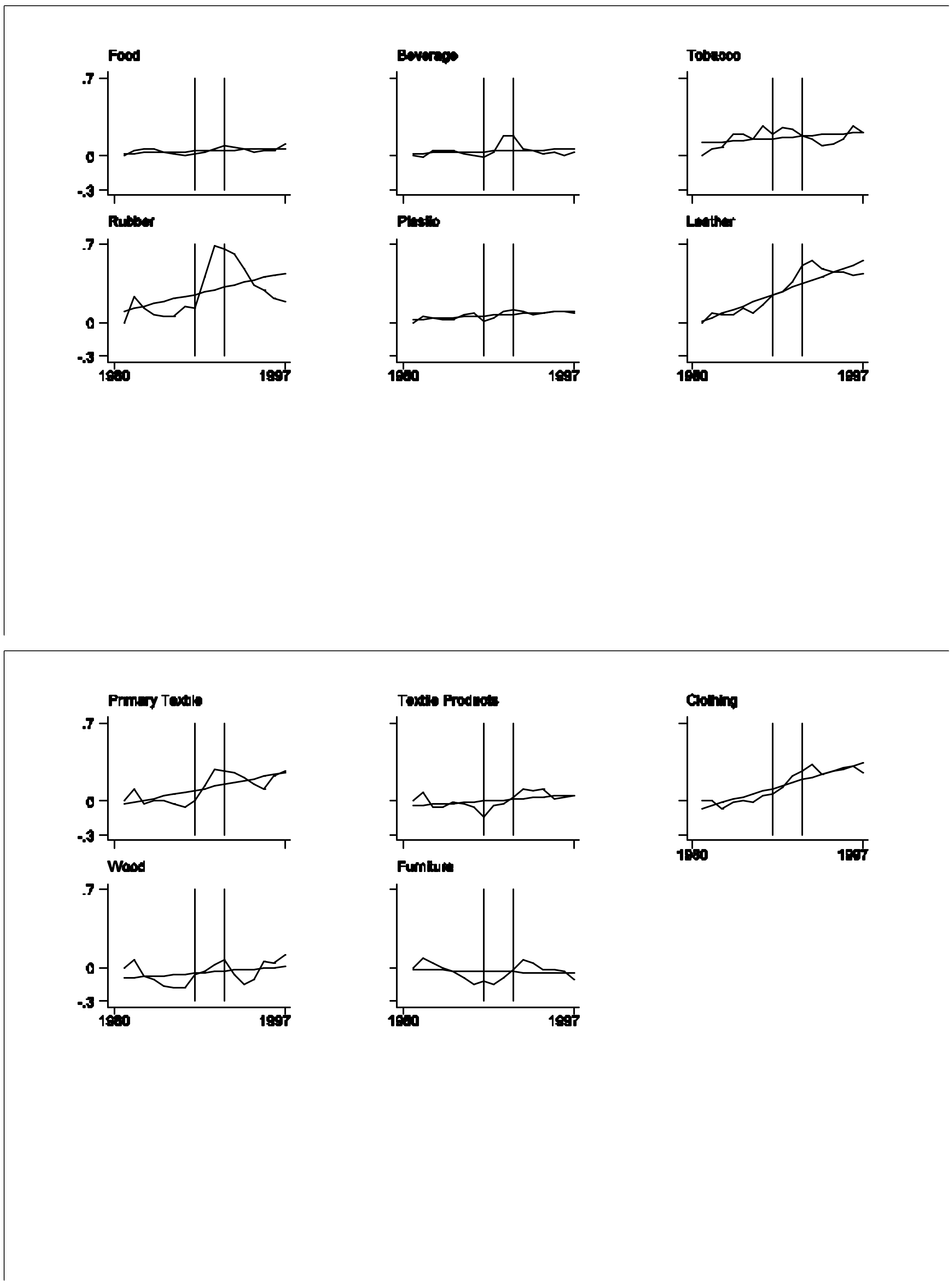
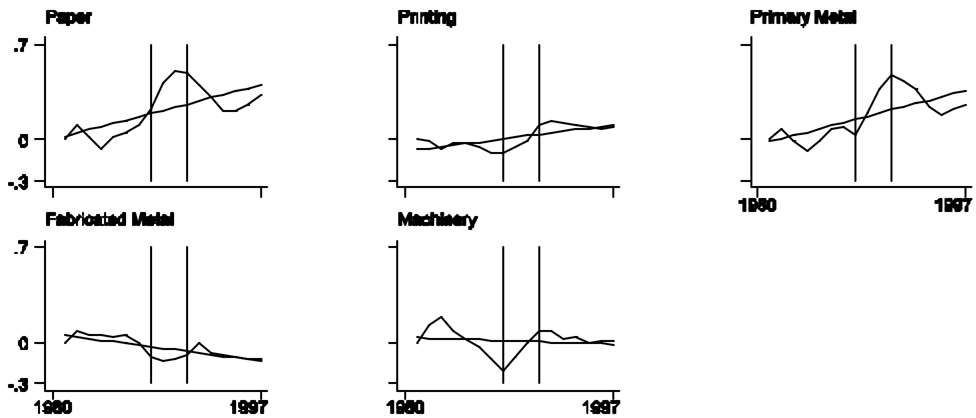


Figure 10. Capital-Labour Ratio in Logs by Industries, 1981–97 (Index 1981 = 0) (cont'd)



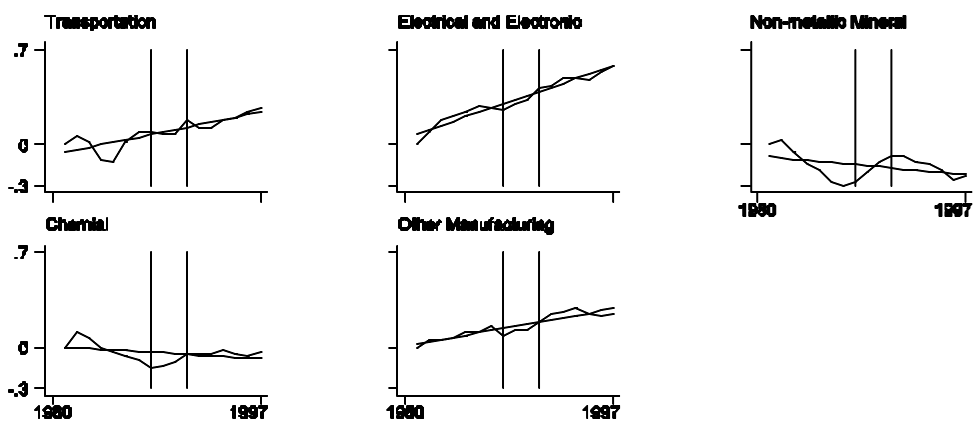


Figure 11. Industry Capital-Labour Ratios and Relative Input Prices

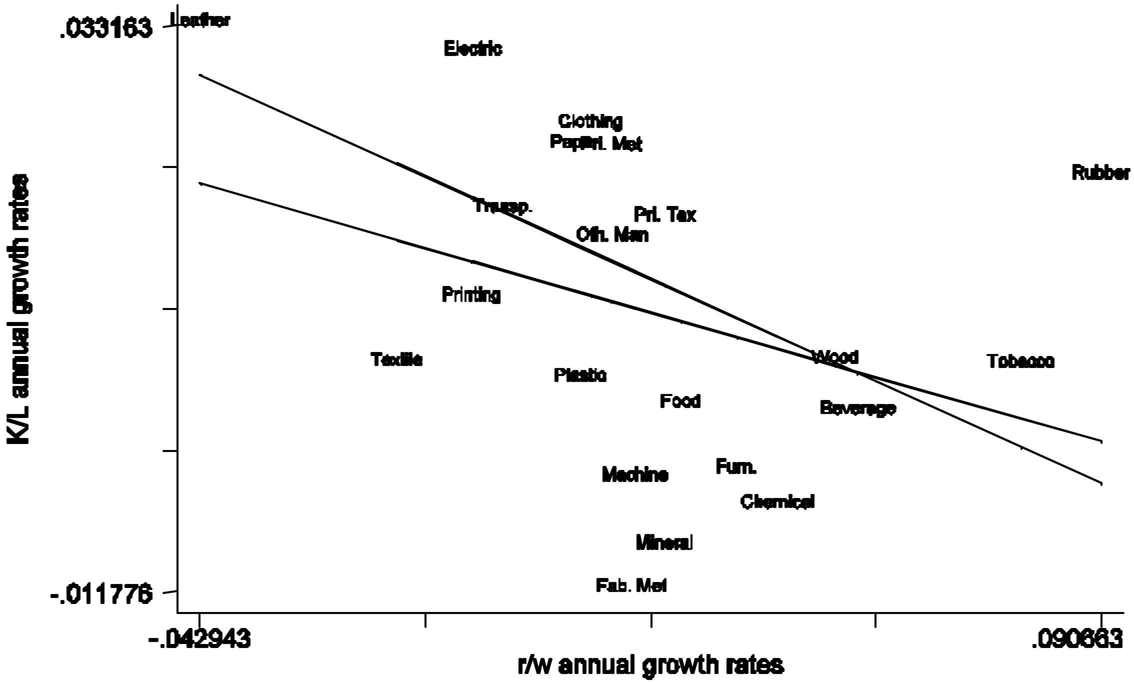


Figure 12. Imported Share of Machinery and Equipment in Manufacturing

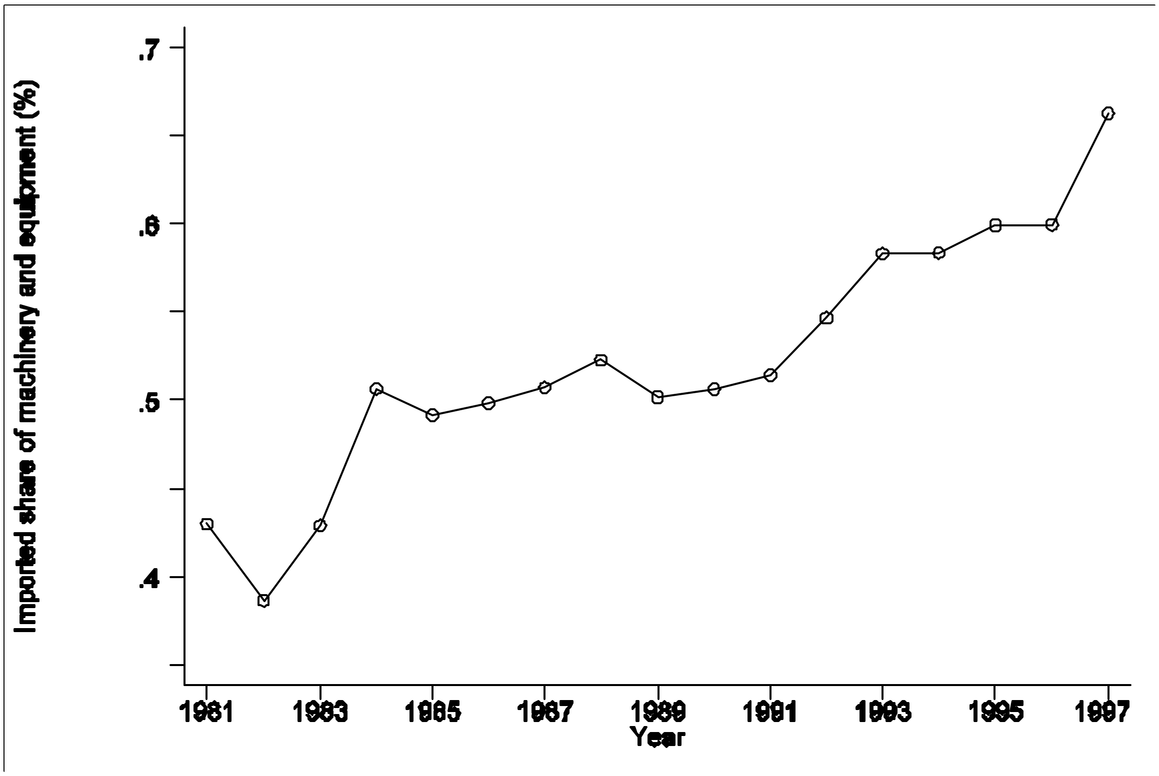
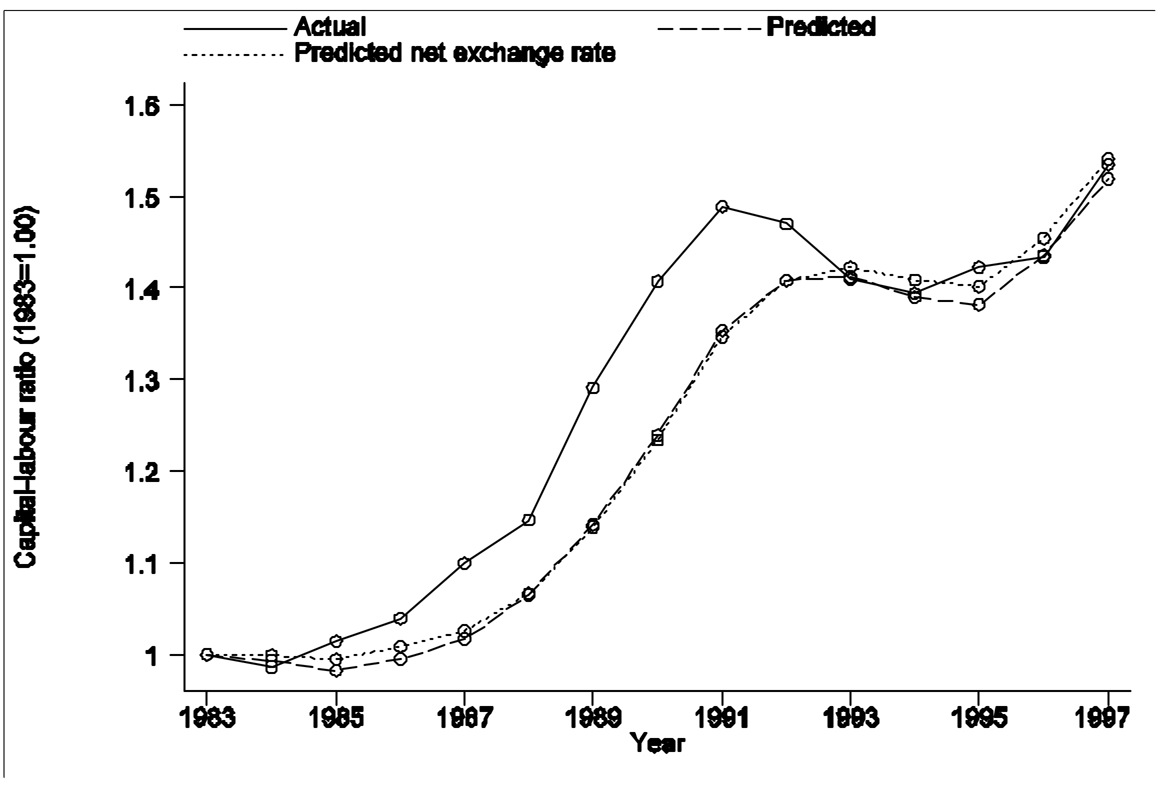


Figure 13. Actual and Predicted M&E-Labour Ratio



Appendix

A1. The *K/L* Ratio in a Dynamic Factor Demand Framework

Let the representative firm maximize the expected present value of all future profits,

$$p_t = \max_{K_{t+t}, L_{t+t}} E_t \left[\sum_{t=0}^{\infty} b^t G\left(K_{t+t}, L_{t+t}\right) - C_K\left(\Delta K_{t+t}\right) - C_L\left(\Delta L_{t+t}\right) \right]. \tag{A1}$$

Taking a second-order Taylor approximation around the long-run equilibrium levels, $\tilde{K}$ and $\tilde{L}$, the net profit function, $G\left(K_t, L_t\right) = p_t Y_t - r_t K_t - w_t L_t$, can be written as:

$$G(L,K) = G\left(\tilde{L}, \tilde{K}\right) + c_{LL}\left(L - \tilde{L}\right)^2 + c_{KK}\left(K - \tilde{K}\right)^2 + c_{LK}\left(L - \tilde{L}\right)\left(K - \tilde{K}\right). \tag{A2}$$

Assuming that the adjustment cost structure of capital and labour takes a quadratic form,

$$C_K\left(\Delta K\right) = \frac{q_K\left(\Delta K\right)^2}{2}, \tag{A3a}$$

$$C_L\left(\Delta L\right) = \frac{q_L\left(\Delta L\right)^2}{2}, \tag{A3b}$$

the maximization problem (A1) subject to (A2) and (A3) yields the optimal demands for K and L that can be expressed as a well-known partial-adjustment equation (Nickell 1984 and 1986):

$$\begin{bmatrix} L_t \\ K_t \end{bmatrix} = V \begin{bmatrix} L_{t-1} \\ K_{t-1} \end{bmatrix} + \sum_{t=0}^{\infty} (bV)^t \left[I - bV\right]\left[I - V\right] E_t \left(\begin{bmatrix} \tilde{L}_{t+t} \\ \tilde{K}_{t+t} \end{bmatrix} \right), \tag{A4}$$

where $V = \begin{bmatrix} v_{L1} & v_{L2} \\ v_{K2} & v_{K1} \end{bmatrix}$ is given by the stable solution of

$$b \begin{bmatrix} q_L & 0 \\ 0 & q_K \end{bmatrix} V^2 - \begin{bmatrix} q_L(1+b) - c_{LL} & -c_{LK} \\ -c_{LK} & q_K(1+b) - c_{KK} \end{bmatrix} V + \begin{bmatrix} q_L & 0 \\ 0 & q_K \end{bmatrix} = 0.$$

In the case where all shocks are permanent $\left(\text{i.e., } E_t\left(\tilde{K}_{t+t}\right) = \tilde{K} \text{ and } E_t\left(\tilde{L}_{t+t}\right) = \tilde{L}\right)$, we can then ignore the expectation operations and equation (A4) becomes

$$\begin{bmatrix} L_t \\ K_t \end{bmatrix} = V \begin{bmatrix} L_{t-1} \\ K_{t-1} \end{bmatrix} + \left[I - V\right] \begin{bmatrix} \tilde{L} \\ \tilde{K} \end{bmatrix}. \tag{A5}$$

Taking a log approximation of equation (A5) and rearranging it,

$$\begin{bmatrix} \log L_t \\ \log K_t \end{bmatrix} - V \begin{bmatrix} \log L_{t-1} \\ \log K_{t-1} \end{bmatrix} = [I - V] \begin{bmatrix} \log \tilde{L} \\ \log \tilde{K} \end{bmatrix}.$$

Therefore,

$$\begin{bmatrix} \log L_t \\ \log K_t \end{bmatrix} = [I - VL]^{-1} [I - V] \begin{bmatrix} \log \tilde{L} \\ \log \tilde{K} \end{bmatrix}.$$

Then, the capital-labour ratio in logs can be expressed as

$$\log\left(\frac{K}{L}\right)_t = (-1 \quad 1) \begin{bmatrix} \log L_t \\ \log K_t \end{bmatrix} = (-1 \quad 1)[I - VL]^{-1} [I - VL] \begin{bmatrix} \log \tilde{L} \\ \log \tilde{K} \end{bmatrix}. \qquad \text{(A6)}$$

Note that the inverse of a square matrix is the adjoint matrix divided by the determinant, $[I - VL]^{-1} = [I - adj(V)L]/[\det(I - VL)]$. We can rewrite equation (A6) as

$$[\det(I - VL)] \log\left(\frac{K}{L}\right)_t = (-1 \quad 1)[I - adj(V)L][I - VL] \begin{bmatrix} \log \tilde{L} \\ \log \tilde{K} \end{bmatrix}.$$

Also note that

$$\det(I - VL) = \left(1 - (v_{L1} + v_{K1})L + (v_{L1}v_{K1} - v_{L2}v_{K2})L^2\right),$$

and

$$[I - adj(V)L] = \begin{bmatrix} 1 - v_{K1}L & v_{L2}L \\ v_{K2}L & 1 - v_{L1}L \end{bmatrix}.$$

Then, equation (A6) can be further simplified to

$$\begin{aligned} \log\left(\frac{K}{L}\right)_t = {} & (v_{L1} + v_{K1}) \log\left(\frac{K}{L}\right)_{t-1} - (v_{L1}v_{K1} - v_{L2}v_{K2}) \log\left(\frac{K}{L}\right)_{t-2} \\ & + [(1 - v_{L1})(1 - v_{K1}) - v_{L2}v_{K2}] \log\left(\frac{\tilde{K}}{\tilde{L}}\right). \end{aligned} \qquad \text{(A7)}$$

A2. Data

A2.1 User cost of capital

The user cost measure is the service value that makes investment in asset *a* worthwhile, given that service values received in future periods are discounted. In the literature, this measure is generally formulated in terms of expected values, because it is based on the principle that the purchase price of an asset equals the discounted present value of its expected future services. In the standard user cost measure, the expected annual service value equals the expected net return on the funds during the year.

Taking into consideration taxes, the user cost of capital, uc_{iat}, may be expressed in the following for the capital asset type *a* in industry *i* at period *t* (Christensen and Jorgenson 1969):

$$uc_{iat} = q_{iat-1}\left\{\left(\frac{1 - v_{it} z_{iat} - k_{iat}}{1 - v_{it}}\right)\left[r_t + t_{ia} - \frac{\left(q^*_{iat} - q_{iat-1}\right)}{q_{iat-1}}\right] + w_{it}\right\}, \qquad \text{(A8)}$$

where *q* is the price of capital, *a*, and *r* is the interest payment if a loan is taken out to acquire the asset. Alternatively, *r* can be interpreted as the opportunity cost of employing capital elsewhere than in production. *t* is the cost of depreciation or the loss in value of the machine because it ages. The loss in value reflects physical decay or efficiency loss of the asset, but also the fact that its expected service life has declined by one period. *w* is the effective rate of property taxes (nominal valued taxes assessed on the real stocks of land and structures), and $\left(\frac{1 - vz - k}{1 - v}\right)$ is the effective rate of taxation on capital income, where *v* is the corporate income tax rate, *z* is the present value of depreciation deductions for tax purposes on a dollar's investment in capital type *a* over the lifetime of the investment, and *k* is the rate of the investment tax credit; $\frac{\left(q^*_{iat} - q_{iat-1}\right)}{q_{iat-1}}$ is the expected capital gain.

A2.2 Imported share of machinery and equipment in manufacturing

The imported share of machinery and equipment for the entire manufacturing industry can be estimated using the input-output tables in the following way.

Let $j = 1, 2, \ldots, J$, index the *J* commodities in which investment in machinery and equipment take place. The commodities in which investment in machinery and equipment are made can be identified in the final demand matrix. For each machinery and equipment commodity, the imported share of the commodity *j*, S_j can be computed in the following way:

$$S_j = \frac{M_j - RX_j}{O_j + \left(M_j - RX_j\right) - X_j - INV_j},$$

where *M* is the imported value, *RX* is the amount re-exported, *X* is the value of exports, *O* is gross output, and *INV* is additions to inventories. The numerator represents the amount of imported commodity j available for domestic use, while the denominator represents the total amount of commodity j available for domestic use.

Given these imported shares by commodity, the share of machinery and equipment can be estimated as:

$$ME^{imp} = \sum_{j=1}^{J} S_j \cdot ME_j \Big/ \sum_{j=1}^{J} ME_j \ ,$$

where ME_j is the investment in type j machinery and equipment for the entire manufacturing industry.

A3. Dynamic Panel Estimators

For ease of illustration, let us consider a simple autoregressive model:

$$y_{it} = a y_{it-1} + h_i + n_{it},$$

for $i = 1, \ldots, N$ and $t = 2, \ldots, T$, where h_{it} is the unobserved individual fixed effects and n_{it} is white noise. It is well known that, for dynamic panels where the time dimension, T, is small relative to the number of cross sections (N), the standard within-groups estimation produces biased and inconsistent estimates for the autoregressive coefficient. Nickell (1981) derives an expression showing that the bias approaches zero only when T goes to infinity. Judson and Owen (1999) show that the bias can be substantial even for $T = 20$.

Various instrumental variable techniques have been developed to generate a consistent estimate of a . Anderson and Hsiao (1982) first-difference the data and then use lagged variables in levels as instruments. Basing their approach on similar ideas, Arellano and Bond (1991) develop a GMM estimator that uses lags of two periods or more as valid instruments. There are $0.5(T-1)(T-2)$ linear moment conditions:

$$E(y_{it-s} \Delta n_{it}) = 0 \text{; for } t = 3, \ldots, T \text{ and } 2 \le s \le t-1. \qquad \text{(A9)}$$

These conditions rely on only two assumptions. First, the error terms, n_{it}, are not serially correlated. Second, the initial value of y is not correlated with the error terms; i.e., $E(y_{i1} v_{it}) = 0$, for $i = 1, \ldots, N$ and $t = 2, \ldots, T$.

Alonso-Borrego and Arellano (1999) show that lagged levels can be weak instruments for equations in first differences. In particular, when the autoregressive parameter on a lagged dependent variable is moderately large for a short panel, the Arellano-Bond GMM estimator is subject to large finite bias and imprecision. To address this issue, Blundell and Bond (1998) develop a system of GMM estimator based on additional moment conditions in levels:

$$E(n_{it} \Delta y_{it-1}) = 0 \text{; for } t = 3, \ldots, T. \qquad \text{(A10)}$$

In addition to the set of moment conditions (A9) that use lagged levels as instruments for first-differenced equations, the $T-1$ moment conditions in (A10) use lagged differences of the dependent variable as instruments for equations in levels. The additional moment restrictions depend on the assumption that Δy_{it} and the individual fixed effects, h_{it}, are uncorrelated. This requires y_{it} to be mean stationary.

In theory, the system GMM estimator developed in Blundell and Bond's (1998) estimator is an improvement upon the Arelleno-Bond estimator. Monte Carlo simulations in Blundell and Bond (1998) show that imposing the additional restrictions substantially reduces the finite sample biases for short sample periods. There is also an improvement in the precision of the estimated parameters for longer panels.

One reason why the Blundell-Bond estimator is not used in this paper is there is evidence that the mean stationary assumption is violated. Im, Pesaran, and Shin's (1997) panel unit root test is used to test the null hypothesis that all series are non-stationary. The null hypothesis is generally accepted. *P*-values range from 0.162 and 0.972, depending on whether a deterministic trend is allowed and how many lagged differences (up to four) are allowed. Hadri's (2000) test is used to test the null hypothesis that all series are stationary. The null hypothesis is rejected at the 1 per cent level, regardless of whether a trend is allowed and regardless of the degree of autocorrelation assumed in the error term.

A4. The Effect of the Relative Price of Capital on *K/L* by Type of Capital

In this section, the preferred estimates in Table 3 are presented along with the results for different lag lengths.

Table A-1. The Effect of the Relative Price of M&E

	(1) $j = 0$	(2) $j = 1$	(3) $j = 2$	(4) $j = 3$
$\log(K/L)_{t-1}$	0.7044	0.7698	0.7806	0.8678
	(0.1023)	(0.1031)	(0.1107)	(0.1139)
$\log(K/L)_{t-2}$	-0.3313	-0.2723	-0.2878	-0.2834
	(0.0701)	(0.0523)	(0.0621)	(0.0637)
$\log(r/w)_t$	-0.2089	-0.1446	-0.1625	-0.2231
	(0.0557)	(0.0647)	(0.0678)	(0.0678)
$\log(r/w)_{t-1}$		0.0131	0.0191	0.0659
		(0.0753)	(0.0803)	(0.0823)
$\log(r/w)_{t-2}$			0.0024	0.0744
			(0.0271)	(0.0383)
$\log(r/w)_{t-3}$				-0.0469
				(0.0483)
$\frac{\sum \log(r/w)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.3333	-0.2617	-0.2780	-0.3123
	(0.0852)	(0.1447)	(0.1465)	(0.2119)
$\log Y_t$	0.1439	0.1380	-0.1388	-0.0113
	(0.0896)	(0.1103)	(0.1160)	(0.1420)
$\log Y_{t-1}$		0.3196	0.3431	0.1637
		(0.1543)	(0.1487)	(0.1210)
$\log Y_{t-2}$			-0.0586	-0.1447
			(0.0735)	(0.0759)
$\log Y_{t-3}$				0.0690
				(0.1002)
$\frac{\sum \log(Y)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	0.2295	0.3615	0.2872	0.1846
	(0.1514)	(0.2782)	(0.3303)	(0.5267)
Akaike	-4.6839	-4.6658	-4.6564	-4.5522
Schwartz	-4.4208	-4.4027	-4.3932	-4.2746

Table A-2. The Effect of the Relative Price of Other M&E

	(1) $j = 0$	(2) $j = 1$	(3) $j = 2$	(4) $j = 3$
$\log(K/L)_{t-1}$	0.8605 (0.0869)	0.9203 (0.0860)	0.9165 (0.0896)	0.9513 (0.0956)
$\log(K/L)_{t-2}$	-0.3941 (0.0708)	-0.3189 (0.0491)	-0.3379 (0.0582)	-0.3267 (0.0589)
$\log(r/w)_t$	-0.1743 (0.0505)	-0.1407 (0.0551)	-0.1864 (0.0604)	-0.2131 (0.0662)
$\log(r/w)_{t-1}$		0.0770 (0.0540)	0.0650 (0.0622)	0.0814 (0.0684)
$\log(r/w)_{t-2}$			0.0734 (0.0375)	0.1123 (0.0403)
$\log(r/w)_{t-3}$				-0.0079 (0.0570)
$\dfrac{\sum \log(r/w)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.3265 (0.0910)	-0.1599 (0.1639)	-0.1139 (0.1617)	-0.0725 (0.2706)
$\log Y_t$	0.1127 (0.0751)	-0.1580 (0.1165)	-0.2006. (0.1392)	-0.1045 (0.1709)
$\log Y_{t-1}$		0.2244 (0.1320)	0.3091 (0.1400)	0.1298 (0.1103)
$\log Y_{t-2}$			-0.2518 (0.0835)	-0.2164 (0.0776)
$\log Y_{t-3}$				-0.0126 (0.1072)
$\dfrac{\sum \log(Y)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	0.2112 (0.1449)	0.1667 (0.2744)	-0.3399 (0.2725)	-0.5423 (0.6199)
Akaike	-4.5464	-4.5226	-4.5258	-4.4731
Schwartz	-4.2833	-4.2595	-4.2626	-4.1954

Table A-3. The Effect of the Relative Price of ICT

	(1) $j = 0$	(2) $j = 1$	(3) $j = 2$	(4) $j = 3$
$\log(K/L)_{t-1}$	0.6917	0.6794	0.6839	0.6705
	(0.1083)	(0.1066)	(0.1053)	(0.1192)
$\log(K/L)_{t-2}$	-0.0007	0.0042	0.0004	-0.0361
	(0.0868)	(0.0848)	(0.0849)	(0.0823)
$\log(r/w)_{t}$	-0.0032	0.0047	-0.0203	-0.0796
	(0.0845)	(0.1115)	(0.0966)	(0.1149)
$\log(r/w)_{t-1}$		0.0762	0.0958	0.1318
		(0.0490)	(0.0568)	(0.0976)
$\log(r/w)_{t-2}$			-0.0312	-0.0491
			(0.0753)	(0.0941)
$\log(r/w)_{t-3}$				-0.0120
				(0.0575)
$\frac{\sum \log(r/w)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.0103	0.2557	0.1400	-0.0243
	(0.2730)	(0.3260)	(0.3549)	(0.3561)
$\log Y_{t}$	-0.2820	-0.6594	-0.6638	-0.5242
	(0.1691)	(0.2669)	(0.2799)	(0.2988)
$\log Y_{t-1}$		0.3958	0.4406	0.2600
		(0.1987)	(0.2087)	(0.2454)
$\log Y_{t-2}$			-0.0351	0.0207
			(0.1371)	(0.1660)
$\log Y_{t-3}$				0.0498
				(0.1573)
$\frac{\sum \log(Y)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.9128	-0.8332	-0.8183	-0.5295
	(0.5717)	(0.6205)	(0.7108)	(0.7113)
Akaike	-3.5529	-3.5650	-3.5604	-3.3904
Schwartz	-3.2898	-3.3019	-3.2973	-3.1128

A5. Difference versus Level Instruments

Panel unit root tests suggest that capital-labour ratio series are non-stationary. As a result, the validity of using lagged levels as instruments may be problematic. Potential problems can be avoided by using lagged differences as instruments. Table A-4 compares estimates of long-run elasticities that use level instruments with those that use differenced instruments. In most cases, the estimates are similar. The exception is Table 5, column 2, (the regression for M&E during the 1981–89 period with one lag of the relative price). In that case, the long-run elasticity becomes larger and more significant.

Table A-4. Long-Run Elasticities, Differenced versus Level Instruments

		Differenced	Level
Table 3, column 1 Table A-1, column 1	$\frac{\sum \log(r/w)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.2816 (0.0734)	-0.3333 (0.0852)
Table A-2, column 2		-0.3093 (0.1059)	-0.2617 (0.1447)
Table 5, column 1		-0.1604 (0.1355)	-0.0779 (0.1803)
Table 5, column 2		-0.4654 (0.1372)	-0.2882 (0.2038)
Table 5, column 3		-0.3206 (0.0833)	-0.3070 (0.0864)
Table 5, column 4		-0.3324 (0.1332)	-0.2685 (0.1100)
Table 6, column 1	$\frac{\sum \log r_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.2789 (0.0557)	-0.2877 (0.0708)
	$\frac{\sum \log w_{t-j}}{1-\sum \log(K/L)_{t-j}}$	0.8309 (0.3939)	0.8395 (0.3754)

A6. Controlling for Time Effects

This paper uses industry-specific time trends to control for unexplained changes in the capital-labour ratio. Ouellette and Vigeant (2003) argue that technological change and changing trade regulations affect investment behaviour. They estimate investment and factor demand functions for 15 Canadian manufacturing industries for the 1962–93 period, and find that both exogenous technological change and changing regulations have an effect on investment behaviour and the input mix. However, the strength of these effects varies across industries. If time dummies are used, time effects are restricted to be the same across all industries. Industry-specific trends allow effects to vary across industries, but restrict time effects to be linear. This may not be optimal, because the strongest increase in the capital-labour ratio took place in the years after the Free Trade Agreement. Using both makes the variation in the data used to identify the effects of the relative price difficult to interpret. Table A-5 shows that the main results of this paper are not greatly affected by the way time effects are controlled.

Table A-5. Long-Run Elasticities, Time Dummies, and Industry-Specific Time Trends

		Industry time trends	Time dummies	Time dummies and industry time trends
Table 3, column 1	$\frac{\sum \log(r/w)_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.3333	-0.3438	-0.3665
		(0.0852)	(0.1185)	(0.1157)
Table A-1, column 1				
Table A-2, column 2		-0.2617	-0.1983	-0.1527
		(0.1447)	(0.1803)	(0.2164)
Table 5, column 1		-0.0779	-0.2214	-0.2482
		(0.1803)	(0.1605)	(0.1562)
Table 5, column 2		-0.2882	0.0494	-0.2863
		(0.2038)	(0.3026)	(0.1992)
Table 5, column 3		-0.3070	-0.4931	-0.2740
		(0.0864)	(0.2145)	(0.1637)
Table 5, column 4		-0.2685	-0.4734	-0.1499
		(0.1100)	(0.2218)	(0.1566)
Table 6, column 1	$\frac{\sum \log r_{t-j}}{1-\sum \log(K/L)_{t-j}}$	-0.2877	-0.3116	-0.3519
		(0.0708)	(0.1084)	(0.1291)
	$\frac{\sum \log w_{t-j}}{1-\sum \log(K/L)_{t-j}}$	0.8395	1.2137	1.0955
		(0.3754)	(0.5336)	(0.5585)

A7. Attempts to Directly Estimate the Effect of the Exchange Rate

In the main text of this paper, the effect of the exchange rate is obtained through an indirect accounting methodology. The exchange rate could be entered into the regression directly with the relative price, but since the exchange rate and the relative price of M&E are highly correlated (as noted earlier, Figure 6 shows that the fluctuations in the relative price are greater than the fluctuation in the exchange rate), it would be difficult to identify both effects. Furthermore, the coefficient on the exchange rate is difficult to interpret, because there is a direct mechanical link between the exchange rate, the price of imported M&E, and the user cost of M&E. The user cost cannot be held constant when the exchange rate changes. Given the imported share of M&E, an estimate of the relative price of M&E net of the exchange rate changes can be obtained and used as a repressor. The breaking of the mechanical link between the exchange rate and relative price may be enough to separately identify the effect of the exchange rate. The results are shown in Table A-6. As expected, the exchange rate is not significant when entered with the relative price. On the other hand, the exchange rate is significant when used with the net relative price in Table 3, column 1 (the regression for the M&E-labour ratio for the entire 1981–97 period with no lags of the relative price). Unfortunately, this result is not robust, because the exchange rate is not significant in any of the other regressions.

The results of this exercise are disappointing, except in one respect. If one takes the view that the relative price is not constructed appropriately by Statistics Canada, then the relative price used in this paper is a noisy measure of the true relative price. The net relative price, which arguably removes most of this noise, is significant and has approximately the same magnitude as the relative price.

Table A-6. Long-Run Elasticities, Direct Effect of the Exchange Rate

	Baseline[2]	Baseline w/ exchange rate[3]		Net relative price w/ exchange rate[4]	
	Relative price[1]	Relative price[1]	Exchange rate	Net relative price[1]	Exchange rate
Table 3, column 1	-0.3333	-0.2590	-0.2404	-0.2584	-0.3940
Table A-1, column 1	(0.0852)	(0.0783)	(0.219)	(0.0780)	(0.2068)
Table A-2, column 2	-0.2617	-0.1738	-0.1994	-0.1905	-0.3122
	(0.1447)	(0.1673)	(0.390)	(0.1594)	(0.2839)
Table 5, column 1	-0.0779	-0.1723	0.0932	-0.1893	0.0066
	(0.1803)	(0.1812)	(0.2656)	(0.1737)	(0.2401)
Table 5, column 2	-0.2882	-0.2540	-0.0848	-0.2681	-0.2050
	(0.2038)	(0.2058)	(0.3176)	(0.2013)	(0.2672)
Table 5, column 3	-0.3070	-0.3392	0.1500	-0.3269	-0.0659
	(0.0864)	(0.1271)	(0.3432)	(0.1270)	(0.2965)
Table 5, column 4	-0.2685	-0.2755	0.0702	-0.2588	-0.1027
	(0.1100)	(0.1092)	(0.3572)	(0.1108)	(0.3490)
Table 6, column 1	-0.2877	-0.2607	-0.0871	-0.2657	-0.2167
	(0.0708)	(0.0891)	(0.2246)	(0.0884)	(0.2024)
	0.8395	0.7587		0.7688	
	(0.3754)	(0.3509)		(0.3508)	

1. For the last row, the long-run elasticities are for the user cost of capital and the price of labour.
2. The baseline specifications are from the tables indicated in the first column.
3. The exchange rate is added as an exogenous regressor to the baseline specifications.
4. The exchange rate is added as an exogenous regressor. Furthermore, the user cost net of the exchange rate effects is now used as a regressor.

Bank of Canada Working Papers
Documents de travail de la Banque du Canada

Working papers are generally published in the language of the author, with an abstract in both official languages. ***Les documents de travail sont publiés généralement dans la langue utilisée par les auteurs; ils sont cependant précédés d'un résumé bilingue*****.**

2005

2004

Copies and a complete list of working papers are available from:
Pour obtenir des exemplaires et une liste complète des documents de travail, prière de s'adresser à :

Publications Distribution, Bank of Canada
234 Wellington Street, Ottawa, Ontario K1A 0G9
E-mail: publications@bankofcanada.ca
Web site: http://www.bankofcanada.ca

Diffusion des publications, Banque du Canada
234, rue Wellington, Ottawa (Ontario) K1A 0G9
Adresse électronique : publications@banqueducanada.ca
Site Web : http://www.banqueducanada.ca