Essays on Canada-US Productivity in Manufacturing

by

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M.A., University of Saskatchewan, 2008

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Supervisory Committee

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Abstract

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Canada and the US are highly integrated economies and yet persistent productivity gaps exist between them. This raises the question whether there is a relationship in productivity between Canada and the US, and if so, what industry-specific characteristics are important. This dissertation focuses on the manufacturing sector and its component three-digit industries. The first chapter investigates the interdependence of labour productivity (LP) between the two countries. It finds no evidence of long-run convergence of US and Canadian LP. There is, however, some evidence of short-run dependence within industries. Regarding industry characteristics, only industry-specific export intensity is found to be an important channel for the long-run productivity transmission.

The second chapter develops measures of total factor productivity (TFP) that are comparable across Canada and the US. The third chapter investigates the interdependence of TFP between the countries. As with LP, there is no evidence of long-run convergence. In both the short and long run, the dependence of Canadian manufacturing industries upon their US counterparts is limited and non-uniform. The fourth chapter examines industry-specific characteristics. Export, import and foreign direct investment (FDI) intensities are found to be important channels in the short run for technology diffusion from the US. Surprisingly, a higher research and development intensity reduces short-run technology diffusion. In the long run, export and FDI intensities are shown to contribute to technology diffusion.

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Chapter 1 Introduction

1.1 Introduction

Canada and the US are highly integrated economies; in addition to extensive bilateral trade and investment, the countries share a common language, have similar market structures and regulation, and have relatively good labour mobility between them. Based upon these features it might be reasonable to expect convergence in industry productivity levels. Numerous studies, however, identify significant and persistent gaps in productivity levels between Canadian and US industries (e.g., Cerisla and Chan-Lau, 2000, Bernstein, Harris and Sharpe, 2002, Baldwin and Gu, 2007, and Tang, Rao and Li, 2010).

This dissertation examines the interdependence of Canadian and US manufacturing industry-level productivities, both labour productivity and total factor productivity (TFP). The objective is to assess the extent to which variation in US industry productivities influences Canadian counterpart industries; that is, the extent of cross-border productivity transmission, or technology diffusion in the case of TFP studies. A possible source for such transmission, consistent with theories of economic convergence, includes the direct transfer of technology and production methods. An alternative or additional source may be competitive pressures that influence productivity outcomes in Canada. A key contribution of this dissertation is to determine whether, and if so to what extent, these sources may be responsible for industry-level productivity interdependence between the two countries.

1.2 Overview of the Dissertation Chapters

Chapter 2 examines the relationship between Canadian and US labour productivity in manufacturing and its component industries. This study finds no evidence of convergence or other long run relationships for manufacturing as a whole or on an industry basis. The study does find, however, some relationship between industry labour productivity growth rates, though the extent of the interdependence between industries in Canada and the US is surprisingly small and varies significantly across industries.

Finally, the study examines whether the industry intensities of exports, foreign direct investment and research and development expenditures have any bearing on the interdependence we do observe; there appears to be some role for export intensity to increase the interdependence between industries across borders.

National statistics offices in different countries, as well as individual researchers, make a range of different assumptions and use different approaches to estimating TFP growth. These methodological choices typically reflect a combination of data availability and the objectives of the study. For example, national statistics offices typically have access to more disaggregated data than outside researchers due to confidentiality considerations. Other differences reflect different theoretical and practical considerations related to, for example, calculations of capital user cost, which can have implications for growth measures of capital input and thereby TFP growth. As a result, TFP growth estimates can vary for a given time period for a country. Chapter 3 uses "reasonably" comparable data for output, labour and capital in Canada and the US to investigate the sensitivity of TFP growth estimates (by industry and for the business sector in the two countries) to three alternative methodological assumptions. This chapter shows that TFP growth estimates for both countries, as well as the Canada-US TFP growth gap, are fairly robust to the alternative methodologies and assumptions considered.

Using the newly developed data set of comparable TFP measures from Chapter 3, Chapter 4 examines the TFP relationships between Canada and the US in the manufacturing sector and its component industries, using standard time series methods on an industry-by-industry basis. The study finds little evidence of long-run convergence in productivity within manufacturing between the two countries. Industry-specific VAR models further suggest that at the industry level productivity technology diffusion from the US to Canadian counterparts is somewhat limited and non-uniform across industries.

Building upon Chapter 4, Chapter 5 seeks to quantify the relationship between US and Canadian TFPs in manufacturing industries, again using the TFP growth estimates developed in Chapter 3. Dynamic panel estimation is employed to determine whether certain industry characteristics thought to influence the diffusion of technology do so in the Canada-US context. The study shows that the US productivity innovations are an important source of Canadian productivity growth, though primarily in the short run rather than the long run. Export, import and foreign direct investment (FDI) intensities are found to be important channels for technology diffusion from the US in the short run. Surprisingly, a higher research and development intensity reduces short-run technology diffusion on average. In the long run, export and FDI intensities are shown to contribute to technology diffusion.

Chapter 6 concludes.

Chapter 2 Canadian and US Manufacturing Labour Productivity: Short and Long Run Relationships

2.1 Introduction

In this study, we examine the relationship between Canada and US labour productivity for manufacturing industries. Our objective is to determine the extent to which Canadian productivity measures depend upon their US counterparts and what influence, if any, industry-specific features have on this dependence.

Canada and the US are closely integrated industrialized economies. Despite this closeness, there are well documented differences in the levels and growth rates of productivity, variously measured, over recent decades. At an aggregate level, Canada lags behind in productivity growth rates and levels; see for example the discussion in Tang and Wang (2004). At a sector or industry level the comparison is not always uniform but in general Canada again lags behind. For a discussion of these comparisons, measurement issues, particularly with respect to multi-factor productivity, the related literature on Canada-US productivity comparisons, see Baldwin, Gu, and Yan (2008). See also Tang, Rao, and Li (2010) and Rao, Tang, and Wang (2004) for an examination of relative productivity measures between Canada and the US at an industry level and Baldwin and Green (2008) for a focus on manufacturing. The well documented existence of productivity gaps, both in growth rates and levels, between the two countries leaves unanswered whether there are any forces that might contribute to closing the differences observed.

We approach this question in two stages. In the first stage, we consider the interdependencies between the two countries on an industry-by-industry basis. We do so using simple bivariate VAR models of Canadian and US labour productivity to examine how US labour productivity innovations affect labour productivity in Canada. What we find is a range of conclusions suggesting, perhaps not surprisingly, that industries differ in this regard. In the second stage, we construct a panel regression model that allows us to identify what role, if any, there is for industry characteristics in explaining these differences. We focus on three characteristics that have been identified in the literature on technology diffusion: export intensity, foreign direct investment intensity, and research and development expenditure intensity.[1]

The paper is structured as follows. We lay out the framework for the empirical analysis in the following section. Section 2.3 discusses the data we use and section 2.4 presents the empirical analysis. Section 2.5 concludes.

2.2 Empirical Framework

Prior to considering the empirical relationships amongst Canadian and US labour productivity, it is useful to develop a simple theoretical representation of industry production so that we can frame the empirical work and discussion appropriately. In this, our approach will differ somewhat from earlier work, such as Bernard and Jones (1996a), in two important ways.

First, we focus exclusively on labour productivity. This has the drawback that the expected interdependence across countries of labour productivities at an industry level is not straightforward as there are no clear predictions from economic theory. Despite this, the focus on labour productivity in contrast to multi-factor productivity is still of interest. For one, labour productivity is a key focus of policy analysis and a standard means of comparing economic performance. Further, labour productivity relates, at least to some extent, to worker compensation and hence general well-being.[2] Finally, multi-factor levels that are comparable across countries, which are required for our analysis, are much harder to measure than labour productivity levels.[3]

Second, we wish to disassociate our analysis from the comparable aggregate analysis in growth theory, which focuses on *convergence* of output per worker premised on the international diffusion of production methods and technology. These models rely on

[1] Keller (2004) is a recent survey of theories and empirical work broadly focused on the international transfer or diffusion of technologies. Bernard and Jensen (1999) and Benjamin and Ferrantino (2001) look specifically at productivity and exporting. Cameron, Proudman and Redding (2005) also focuses on these characteristics in a study similar to this but for the UK and theUS.

[2] Though in recent years this relationship does not seem to be as strong; see for example Mishel and Gee (2012).

[3] See Baldwin *et al*. (2008) for a more complete discussion of the difficulties.

equilibrium conditions that arise from behavioural assumptions (e.g. constant savings rate in the Solow growth model) that are not immediately relevant for industry analysis.

To explore the relationships between labour productivities within industries across borders, we proceed with simple representations of industry production function and assumptions of industry technology diffusion. The objective is to determine what we can expect under different conditions for the *long-run* behaviour of domestic and foreign labour productivity. The short-run dynamics will be introduced later.

For the domestic and foreign economy, let production in some industry be Cobb-Douglas:

$$Y_t = A_t H_t^{\gamma} K_t^{1-\gamma} \qquad\qquad Y_t^* = A_t^* (H_t^*)^{\delta} (K_t^*)^{1-\delta}$$

where Y_t is the industry output, H_t is labour input (hours worked), K_t is capital input and A_t is technology, or total factor productivity. The * denotes foreign. In terms of labour productivity, $X_t \equiv Y_t / H_t$, we have:

$$X_t = A_t (K_t / \mathrm{H}_t)^{1-\gamma} \qquad\qquad X_t^* = A_t^* (K_t^* / \mathrm{H}_t^*)^{1-\delta}$$

If it were the case that domestic and foreign production functions were the same and both had access to common technology (that is, $\gamma = \delta$ and $A_t = A_t^*$), then we would expect domestic and foreign labour productivity to be equal (in the long run). At least, as long as firms are maximizing profits in both countries and no other constraints are imposed on production decisions. In this case, $X_t = X_t^*$ and $x_t = x_t^*$ where $x_t \equiv \log X_t$ and $x_t^* \equiv \log X_t^*$. Empirically, we would expect x_t and x_t^* to be linearly related for each industry with a unit long-run elasticity. If it were the case that x_t and x_t^* were random walks with drifts, which will be our working assumption, then we would expect x_t and x_t^* to be cointegrated with a (1, −1) cointegrating vector. Equivalently, we would expect the productivity gap, $z_t \equiv x_t - x_t^*$, to be stationary.

If instead it were the case that technology was identical across the two countries but otherwise the production methods differed somewhat, then we may or may not get a cointegrating vector for x_t and x_t^*; it will depend upon the relative capital intensities for the industries. Specifically, if $A_t = A_t^*$, we get the following:

$$X_t = X_t^* \left[\frac{(K_t / H_t)^{1-\gamma}}{(K_t^* / H_t^*)^{1-\delta}} \right] = X_t^* C_t$$

If C_t, the relative capital intensity measures, is stationary (in logarithms) then again we would expect x_t and x_t^* to be cointegrated with a (1, −1) cointegrating vector; otherwise the productivity gap, $z_t \equiv x_t - x_t^*$, will not be stationary.

Finally, we can relax the restriction that technology is common across the two countries. Instead, we can assume that the following steady state relationship links the two as follows:

$$A_t = e^{\alpha} (A_t^*)^{\beta}$$

This allows for the possibility that domestic technology is always a fraction of foreign technology ($\alpha \neq 0$) and the possibility that domestic and foreign technology grow at different rates ($\beta \neq 1$). The former might arise because of differences in the business environment, say due to regulations, while the latter might arise due to different investments in research and development. Both of course depend upon some force that prevents the perfect transfer of technology between the two countries. In this case, we get the following for labour productivities:

$$X_t = e^{\alpha} (X_t^*)^{\beta} \left[\frac{(K_t / H_t)^{1-\gamma}}{(K_t^* / H_t^*)^{\beta(1-\delta)}} \right] = e^{\alpha} (X_t^*)^{\beta} \tilde{C}_t$$

Under the assumption that the relative capital intensity term is stationary (in logarithms), we get the following linear long-run relationship for labour productivity in logarithms:

$$x_t = \alpha + \beta x_t^* + \tilde{c}_t$$

In what follows, we will examine first whether $z_t \equiv x_t - x_t^*$ is stationary, which might be plausible if the industries are very similar across the two countries. Because of possible measurement error in terms of the labour productivities, it will always be prudent to allow for a non-zero constant term even under this strong hypothesis. Our second step will be to consider whether or not x_t and x_t^* are cointegrated, again with a non-zero constant tem but allowing for a non-unit long-run elasticity.

Notice that our specification of technology transfer, which most generally we have as: $A_t = e^{\alpha}(A_t^*)^{\beta}$, gives rise to an error correction model for technology under the assumption that foreign technology is, in logarithms, a random walk with drift. This is closely related to the model of technology diffusion specified in Bernard and Jones (1996a), which posits and then tests whether *relative* multi-factor productivity levels, or gaps, are stationary around a zero mean. If true, this implies *convergence* in technology levels and is consistent with $A_t = A_t^*$ as discussed above. If the gaps are stationary with a non-zero mean then this implies convergence in growth rates for technology but not technology levels. So our analysis on labour productivity gaps, conditional on the residual capital intensities being stationary, is analogous to Bernard and Jones (1996a) focus.[4] Our analysis also relates to Cameron, Proudman and Redding (2005), which examines multi-factor productivity growth in the UK at an industry level, dependent upon the productivity gap between the UK and the US; that is, they specify an error correction model (with a unit elasticity) in a panel framework for UK industries.

Where we differ from these papers is allowing for non-unit elasticities on the long-run relationship between multi-factor productivities and hence on labour productivities. We do this for practical reasons firstly; for our data, labour productivity gaps between US and Canadian industries are not stationary, so it is natural to relax the coefficient restriction. Moreover, we do not have strong *a priori* reasons to suppose that labour productivity grows asymptotically at a common rate within an industry across the two countries. This may be because the underlying technology processes do not grow asymptotically at the same rate or perhaps because our decompositions above over-simplify the relationship between technology and the other inputs so that it would be imprudent to impose this

[4] Bernard and Jones (1996a) is explicitly focused on the question of testing whether or not convergence holds for multi-factor productivity in the data. In contrast, we are attempting to model the relationships between industry labour productivities, which requires more flexibility. See their paper for a more general discussion of tests of convergence in terms of productivity.

restriction. Most importantly, from an empirical modelling perspective, when we model labour productivity growth rates we need to know if an error correction term is necessary and its nature.

With this framework as a background, we can now be more specific in laying out the empirical models. We extend the notation above to identify specific industries. For Canada, let x_{it} be labour productivity, in logarithms, for industry i at time t. For the US, denote the same quantity as x_{it}^*. Define the labour productivity gap for industry i as: $z_t \equiv x_t - x_t^*$. (Details of the specific data are discussed in the next Section.)

We begin by first establishing that the labour productivity series, x_t and x_t^*, are all first difference stationary processes with possibly nonzero drift. The next step, as described above, is to consider whether or not there is evidence of *convergence* in each industry; Bernard and Jones (1996a) following Bernard and Durlauf (1995) define convergence as the situation where z_{it}, the productivity gap, is stationary. Should the z_{it} be stationary, then this suggests that a vector error correction model is appropriate for Canadian and US labour productivity growth rates with z_{it} the error correction term. This type of model for productivity growth underlies the model of catch-up used in Dowrick and Nguyen (1989), Bernard and Jones (1996a) as well as Cameron *et al.* (2005). As we demonstrate below, however, z_{it} is not stationary for most (all) of our industries, evidence against the convergence hypothesis; this is consistent with Bernard and Jones (1996b), which finds no evidence of convergence for the aggregate manufacturing sector across OECD economies.

While z_{it} may not be stationary, it remains possible that some other linear combination of x_{it} and x_{it}^* is stationary; as discussed above, we may wish to relax the unit elasticity assumption. To do so, we test for cointegration between US and Canadian industry labour productivities. While there are some exceptions, for the most part we find no evidence of cointegration. This suggests that the appropriate modelling strategy is in terms of labour productivity growth rates with no error correction (convergence) term. This underlies the following two classes of models we estimate.

2.2.1 Industry-Specific Bivariate VAR Models

Our first strategy is to focus on each industry separately using simple bivariate SVAR models of US and Canadian labour productivity. In order to identify the effect of US-based labour productivity on the Canadian counterparts, we assume a simple recursive ordering of US and Canadian labour productivity. This amounts to treating contemporaneous US labour productivity as exogenous for Canadian labour productivity while excluding contemporaneous Canadian labour productivity from the regression equation for US labour productivity. That is, for each industry *i*, we have:

$$
\begin{aligned}
\Delta x_{it}^{*} &= c_1 + b_{11}^{1}\Delta x_{it-1}^{*} + b_{12}^{1}\Delta x_{it-1} + u_{1t} \\
\Delta x_{it} &= c_2 + b_{21}^{0}\Delta x_{it}^{*} + b_{21}^{1}\Delta x_{it-1}^{*} + b_{22}^{1}\Delta x_{it-1} + u_{2t}
\end{aligned}
$$

for $t = 2 \ldots T$ with $Eu_{1t} = u_{2t} = 0$; $Eu_{1t}^2 = \sigma_1^2$; $Eu_{2t}^2 = \sigma_2^2$; $Eu_{1t}u_{2t} = 0$. For ease of notation, we have not indicated the dependence of the coefficients or disturbances on industry *i*. For the same reason, we have presented the model with a lag order of one.[5]

Within this frame work, we can consider the effects of US labour productivity shocks on their Canadian counterpart, in particular the cumulative impact, as well as the overall contribution of US based innovations to variation in Canadian labour productivity growth (through the forecast error variance decompositions). In this way, these models provide a simple means of describing the short run as well as the long run dynamics between US and Canadian labour productivities on an industry-by-industry basis.[6]

2.2.2 Dynamic Panel Models of Labour Productivity and Industry Characteristics

A common theme in the productivity literature is the role for certain industry characteristics to facilitate, directly or indirectly, the speed of productivity improvements. Keller (2004) provides a detailed discussion; see also Cameron *et al.* (2005). The

[5] The SVAR model above is equivalent to the more standard presentation of a reduced form VAR model with a Choleski decomposition on the disturbances. We present it in this format because it is closely related to the dynamic panel model we specify below.

[6] Even though the two series for each industry are not cointegrated, they still have unit roots so that shocks can have permanent effects on labour productivity levels. The cumulative impulse response function will provide information in this regard. One criticism of the above model is that it is possible for Canadian labour productivity shocks to have permanent effects on US labour productivity (and vice versa). An alternative identification strategy would be to restrict long run effects; say, for example, to restrict the long run effects of Canadian labour productivity shocks on US labour productivity. Doing so has little effect on any of our conclusions.

industry characteristics we consider are (1) export intensities; (2) foreign direct investment intensities; and (3) research and development intensities. In each case, we expect that greater intensity will increase the interdependence of domestic labour productivity on the labour productivity in the foreign counterpart. For export intensity, this might arise because of greater competitive pressures felt by relatively open industries. For foreign direct investment (FDI) intensity, this might arise due to the transfer of production methods from abroad. It may also arise from competitive trade pressures since FDI is often associated with multinationals locating domestically to facilitate trade. Finally, research and development (R&D) expenditure is likely to facilitate directly the take up of best production methods. Of course, we would also expect these variables to be highly co-linear, meaning that it may be difficult to distinguish specific roles for each.

The dynamic panel model we consider is similar in principle to the VAR model; now, however, we focus exclusively on the behaviour of Canadian labour productivity. This means we are leaving US labour productivity unspecified and treating it simply as an exogenous variable in our model.

Canadian labour productivity growth is now modelled as:

$$\boldsymbol{\Delta} x_{it} = \beta_0 + \beta_{i1}\boldsymbol{\Delta} x_{it}^{*} + \beta_{i2}\boldsymbol{\Delta} x_{it-1}^{*} + \beta_{i3}\boldsymbol{\Delta} x_{it-1} + \varepsilon_{it}$$

for $t = 2 \ldots T$ and $i = 1 \ldots N$ where N is the number of industries (fifteen). As with the VAR model, we assume a single lag for the dependent variable. In addition to the above, we allow for industry fixed effects, since each industry is likely to have different asymptotic growth rate, and for time effects to capture possible common business cycle effects across all industries. As usual, the fixed effects and time effects can be viewed as components of ε_{it}. The model also allows for industry specific slope coefficients. In the case of the lagged dependent variable, there is no reason *a priori* to restrict these to be the same across industries.

The inclusion of first-order lagged dependent variable is to capture industry-specific growth path in productivity. This, however, introduces potential bias arising from the correlation between the lagged dependent variable and the error term (Nickell, 1981). The bias is due to the finite sample in time dimension, common in microeconomic panels. For larger *T*, as is usually assumed in macroeconomic studies, the bias goes away. How large T must be for the bias to be acceptable is an open question (e.g., Judson and Owen, 1996). For the purpose here, with T = 22, I will proceed with standard estimation and set concerns about this bias aside. The justification for this is that the coefficient on the lagged dependent variable, where the bias arises, is not directly of interest.

For the effects of US labour productivity, we introduce the possibility that these are dependent upon industry characteristics in the following manner. Let w_i denote one of the industry characteristics discussed above; throughout the analysis, due to sample limitations, we consider each industry characteristic in isolation. Then the manner in which US productivity growth contributes to Canadian labour productivity growth is assumed to be:

$$\begin{aligned} \beta_{i1} &= \eta_1 + \delta_1 w_i \\ \beta_{i2} &= \eta_2 + \delta_2 w_i \end{aligned}$$

The first term in each captures the contribution to Canadian labour productivity growth directly from US labour productivity growth, irrespective of the industry characteristics. The second term in each captures the dependence of contribution on the industry characteristics. Our prior, in line with the discussion above, is that all of the coefficients above are positive. Substituting these expressions into the model, we get:

$$\mathbf{\Delta} x_{it} = \beta_0 + \eta_1 \mathbf{\Delta} x_{it}^* + \delta_1 w_i \mathbf{\Delta} x_{it}^* + \eta_2 \mathbf{\Delta} x_{it-1}^* + \delta_2 w_i \mathbf{\Delta} x_{it-1}^* + \beta_{i3} \mathbf{\Delta} x_{it-1} + \varepsilon_{it} \tag{2.1}$$

For estimation, after including the fixed and time effects, we will assume that the model disturbances are serially uncorrelated within the panels and uncorrelated across the panels; however, we have to allow for possible heteroskedasticity across panels. This is discussed further below when we estimate the model.

The above model is very similar in principle to the panel model estimated by Cameron *et al.* (2005); there are two main differences. First, the focus on multi-factor productivity;

second, their framework has productivity growth rates dependent upon the productivity gap from the previous period. Given that the labour productivity gaps for Canada and US manufacturing industries are not stationary, the dependence upon the productivity gap is not relevant for our model.

2.3 Data

2.3.1 Sources and Construction

We measure labour productivity as industry real value added production relative to hours worked by all employees. That is, $x_{it} \equiv \log Y_{it} - \log H_{it}$ where Y_{it} is real value added production in industry i and H_{it} is hours worked. Similar measures are constructed for US labour productivity.

Our data set consists of fifteen manufacturing industries for the period 1987-2007. All data is annual. Statistics Canada provides value added industry output measures in 2002 constant dollars by North American Industry Classification System (NAICS) three-digit classification. The US Bureau of Economic Analysis provides value added industry output measures in 2005 chained dollars again by NAICS three-digit classification. We rebased the US series to 2002; we then used purchasing power parity methods to convert to the Canadian series to 2002 US dollars. To construct suitable purchasing power parities to convert the Canadian series, we use industry specific PPPs, for 2002 from Tang, Rao and Li (2010).

Total hours worked is taken from Statistics Canada CANSIM Table 383-0022. For the US, the US Bureau of Labour Statistics (BLS) provides aggregate weekly hours on a monthly basis by all employees from 2006 onward. Prior to 2005, an annual index of hours worked (2002=100) is provided. By aggregating weekly hours post 2006 and using the index to backcast, we can construct a suitable series of annual hours worked by three-digit NAICS industry for the 1987-2007 period.

2.3.2 Descriptive Summary

The fifteen three-digit industries (or amalgamations of certain industries) are identified in Table 2.1. For each industry and for both Canada and the US, we report the share of overall manufacturing, the average growth rate of labour productivity over the sample, and the productivity gap for each industry at the start and end of the sample.

The shares give a simple measure of the importance of each sector as well as providing a cross-country comparison of the relative importance. For Canada, the four largest industry sectors are (1) transportation equipment; (2) food, beverage, and tobacco products; (3) paper products and printing; and (4) chemical products. Together these account for just over 50 percent of Canadian manufacturing. For the US, the four largest industry sectors, also just over 50 percent of manufacturing, are: (1) transportation equipment; (2) food, beverage, and tobacco products; (3) chemical products; and (4) machinery. Not only is the degree of concentration in manufacturing fairly similar across the two countries (four industries comprising 50 percent of manufacturing in both cases), the large industries for the most part are the same in both countries.

As far as growth rates are concerned, there are a number of notable features. First, overall manufacturing labour productivity growth in the US has been much stronger over this period than in Canada; 4.5 percent relative to 2.5 percent. This comparison, however, is somewhat misleading since it is driven by very high growth (22 percent) for the US in the computer and electronic products industry. If we subtract from this industry, averaging over the other industries in Table 2.1 gives a growth rate of 2.2 percent in both countries.[7] For Canada, the following industries stand out as high growth: (1) wood products; (2) primary metal products; (3) computer and electronic products; and (4) transportation equipment. For the US, (1) textile products; (2) apparel products; (3) computer and electronic products; and (4) the furniture products are the stand-out industries, though of these the growth in the computer and electronic products industry far outstrips the others.

[7] Note that the manufacturing result reported in the table is not the average of the industries reported but the whole of manufacturing, excluding petroleum and coal, as reported by the respective statistical agencies.

Table 2.1 Summary Statistics

NAICS Code	Description	Industry Size (shares, %) CA	Industry Size (shares, %) US	Δx_{it} (mean, %) CA	Δx_{it} (mean, %) US	$\Delta x_{it} - \Delta x_{it}^*$ (%) 1987	$\Delta x_{it} - \Delta x_{it}^*$ (%) 2007
311, 312	Food, beverage, and tobacco	14.2	15.1	1.4	1.2	60.8	63.0
313, 314	Textiles	1.6	2.2	1.4	4.1	84.7	49.0
315, 316	Apparel and leather products	2.5	2.1	1.1	4.3	52.2	27.4
321	Wood products	6.2	2.5	3.7	0.3	85.5	97.6
322, 323	Paper and printing products	10.8	8.8	1.7	1.1	73.5	145.0
325	Chemical products	8.0	13.6	2.4	2.6	60.1	57.9
326	Plastics and rubber products	4.6	4.7	2.1	3.1	95.0	78.1
327	Non-metallic mineral products	2.9	3.3	1.7	1.0	105.3	119.5
331	Primary metal	6.1	3.2	4.2	1.5	97.0	166.0
332	Fabricated metal	6.8	9.3	1.1	1.2	56.5	55.2
333	Machinery	6.6	9.5	2.2	1.8	68.3	73.4
334	Computer and electronic products	3.6	6.4	4.8	21.8	560.6	18.6
335	Electrical equipment	2.2	3.9	1.9	2.3	50.4	46.7
336	Transportation equipment	17.6	15.6	3.9	2.2	71.1	99.6
337, 339	Furniture and miscellaneous	4.5	7.1	2.3	3.6	44.1	34.2
31-33	Manufacturing	100	100	2.5	4.5	95.2	63.5

Note: Sample is 1987-2007. Industry size measures the average of industry value-added relative to total manufacturing value added. Labour productivity in logarithms is x_{it} for Canada, x_{it}^* for US. Industry shares do not add up to 100 due to the exclusion of the petroleum and coal product industries.

Finally, the relative labour productivity measures give a clear indication of the gaps that existed in 1987 between Canadian and US manufacturing and the current gaps in 2007. In 1987, for all but two industries Canadian labour productivity lies below that of the US. These two industries are non-metallic mineral products and, interestingly, computer and electronic products. By the end of the sample, Canada continues to lag behind with the exception of three industries; paper products, non-metallic mineral products (as in 1987), and primary metal products. Notably, labour productivity in the computer and electronic products industry is now 20 percent of what it is in the US.

A visual summary of these industries is also provided in Figures 2.1, which plots labour productivity for each industry (log levels), and Figures 2.2, which plots growth rates for each industry. What is immediately obvious from Figures 2.1 is the lack of any visual evidence of strict convergence on an industry basis. This result will be confirmed more formally in the following section. From Figures 2.2, however, there does appear to be some evidence of correlation in growth rates for some industries, suggesting that some cross-border interdependence between the industries exists.

2.4 Empirical Analysis

2.4.1 General Time Series Properties of Labour Productivities

Table 2.2 reports the Eliot *et al.* (1996) modified Dickey-Fuller (DF) test for a unit root, denoted μ. The null hypothesis, for each industry and for each country, is that labour productivity (in logarithm) has a unit root with non-zero drift. As the productivity series generally exhibit a trend, the test regressions include a linear trend. We consider a maximum lags length of two and select on the basis of the modified Akaike Information Criteria (AIC) due to Ng and Perron (2000). For Canada, we cannot reject the unit root null hypothesis for any of the industries, including manufacturing as a whole, at conventional significance levels. This is also true for the industries in the US with the exception of plastics and rubber products. Inspection of the series in Figure 2.1 indicates a significant trend in the series and the test appears to indicate that the series is best modelled by a linear rather than stochastic trend. Some caution is required, though, as we have a relatively small sample of data and it is always difficult in such situations to discriminate between these two hypotheses.

Figure 2.1 Labour Productivity by Industry and by Sector (Canada: Solid; US: Dashed)

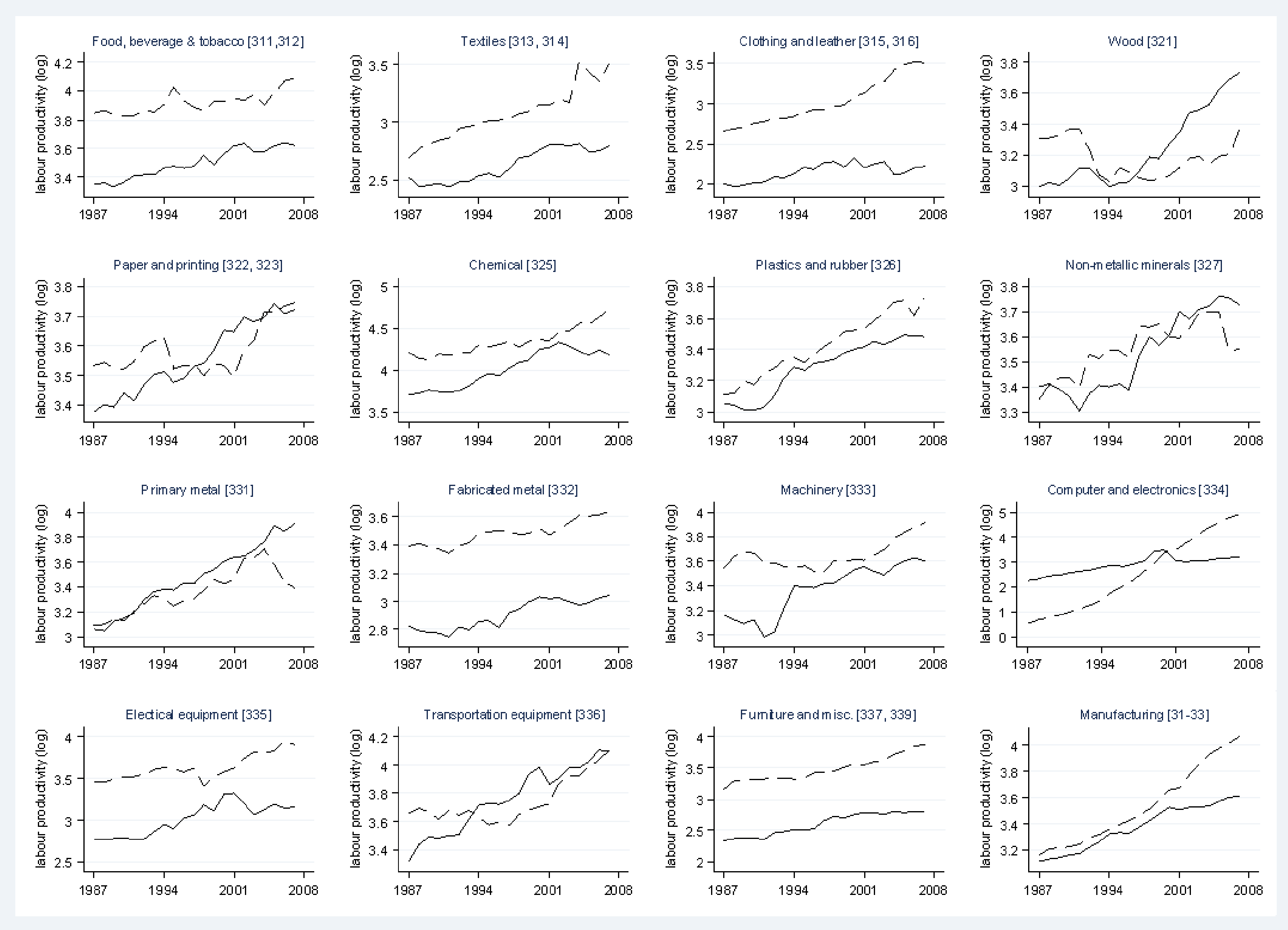


Figure 2.2 Labour Productivity Growth by Sector (Canada: Solid; US: Dashed)

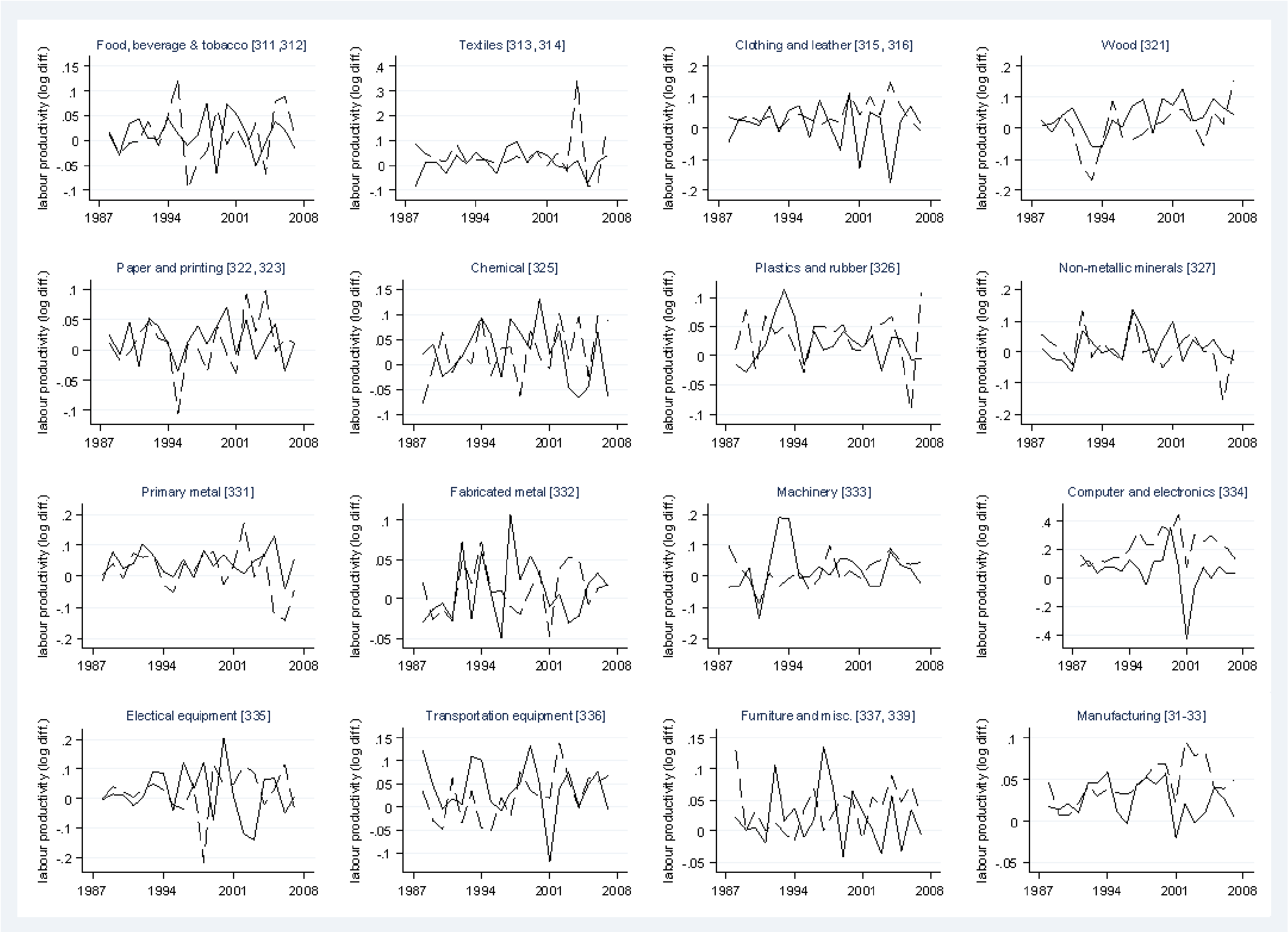


Table 2.2 Unit Root Tests

		Canada				United States			
NAICS		x_{it}		Δx_{it}		x_{it}^*		Δx_{it}^*	
Code	Description	μ	lag	μ	lag	μ	lag	μ	lag
311, 312	Food, beverage, and tobacco	-2.394	2	-4.934***	1	-2.996	1	-3.716***	1
313, 314	Textiles	-1.644	1	-1.096	2	-1.726	2	-2.406*	2
315, 316	Apparel and leather products	-1.073	1	-1.377	1	-1.367	1	-1.606	1
321	Wood products	-1.226	1	-2.274*	1	-1.048	2	-2.419*	1
322, 323	Paper and printing products	-2.167	1	-3.365*	2	-1.355	1	-2.584**	1
325	Chemical products	-1.261	1	-2.079	1	-0.559	1	-0.378	2
326	Plastics and rubber products	-2.347	1	-2.439*	1	-3.899***	1	-4.259***	1
327	Non-metallic mineral products	-1.747	2	-2.391*	2	-1.877	1	-2.442*	1
331	Primary metal	-2.923	1	-2.938***	1	-2.423	1	-2.149	1
332	Fabricated metal	-1.693	1	-1.633	2	-2.533	1	-2.951***	1
333	Machinery	-2.089	2	-3.307***	1	-1.446	1	-1.817	1
334	Computer and electronic products	-1.584	2	-3.900***	1	-1.475	1	-1.768	1
335	Electrical equipment	-1.670	1	-3.173***	1	-1.463	1	-1.752	2
336	Transportation equipment	-2.007	2	-2.458*	2	-0.867	1	-1.718	2
337, 339	Furniture and miscellaneous	-1.688	1	-3.587***	1	-1.304	1	-1.630	1
31-33	Manufacturing	-1.999	1	-2.761***	1	-1.296	1	-2.353*	1

Note: Sample is 1987-2007. μ is the Elliot, Rothenberg, and Stock (1996) Dickey-Fuller statistic for the null hypothesis of a unit root using GLS estimation of the deterministic component. Lag length is chosen using Ng and Perron's (2000) modified AI criteria. Test regressions for productivity levels include a constant and a trend while test regressions for productivity growth rates include a constant and no trend. The notation *, ** and *** denotes significant at 10%, 5% and 1% significance level, respectively, using critical values taken from Cheung and Lai (1995) in *Stata* 11.

As we will be modelling growth rates below, we also test for unit roots in the growth rates (log first differences) and these are also reported in Table 2.2. In this case, we do not include a trend in the test regression. For both the Canadian and US labour productivity growth rates, we reject the unit root hypothesis in most, though not all, cases at standard significance levels. For those instances where we fail to reject, inspection of the associated series and comparison to other growth rate series does not point to any obvious differences; we are left with the somewhat unsatisfactory conclusion that non-stationarity in the growth rates may be a potential problem but given the small samples we cannot be certain. In the subsequent analysis, we will treat the log level series as first difference stationary.

As noted previously, authors such as Bernard and Jones (1996a) examine whether productivity (in logarithm) differentials are stationary, evidence of convergence in productivity. Our focus on labour productivity makes this focus of less interest; nevertheless, we do test whether they are stationary or not. Labour productivity differentials are defined previously for any industry i as $z_t^* \equiv x_t - x_t^*$. As we have (some) evidence of a unit root in each of the labour productivity series, if the productivity gaps are stationary then the two productivity series share a common stochastic trend and, moreover, the associated labour productivity growth rates (one of both) will depend in part upon deviations from this gap. That is, the growth rate series will have an error correction representation with the productivity gap as the error correction term.

The tests for stationarity of the z_{it} are reported in Table 2.3. Following Bernard and Jones and being consistent with our earlier discussion, we do not include a trend in the test regression. The null hypothesis is that the productivity differentials have a unit root; the alternative is that the series are stationary (not trend stationary). As in Table 2.2, we use the DF-GLS test statistic with the lag length chosen by the modified AIC. The results are very clear: we reject the stationarity hypothesis at the 10 percent level or lower.

Table 2.3 Tests for Cointegration between Canada and US Labour Productivity

NAICS Code	Description	CI: $\Delta x_{it} - \Delta x_{it}^{*}$ μ	lag	C.V. [5%, 10%]	CI: $\Delta x_{it} - \beta\Delta x_{it}^{*}$ τ	lag	C.V. [5%, 10%]
311, 312	Food, beverage, and tobacco	-1.175	1	[-2.485, -2.125]	-2.025	1	[-3.022, -2.651]
313, 314	Textiles	-0.448	1		-1.688	1	
315, 316	Apparel and leather products	-0.135	1		-1.653	1	
321	Wood products	-1.154	1		-0.161	1	
322, 323	Paper and printing products	-1.120	1		-1.425	1	
325	Chemical products	-0.988	1		-0.940	1	
326	Plastics and rubber products	-1.387	1		-2.293	1	
327	Non-metallic mineral products	-0.659	1		-0.853	1	
331	Primary metal	-0.349	1		-1.418	1	
332	Fabricated metal	-2.109	1		-2.177	1	
333	Machinery	-1.947	1		-1.984	1	
334	Computer and electronic products	-0.503	1		-2.467	1	
335	Electrical equipment	-1.322	1		-1.418	1	
336	Transportation equipment	-1.183	1		-1.884	1	
337, 339	Furniture and miscellaneous	-1.044	1		-1.556	1	
31-33	Manufacturing	-0.170	1		-1.848	1	

Note: Sample is 1987-2007. μ is the Elliot, Rothenberg, and Stock (1996) Dickey-Fuller statistic for the null hypothesis of a unit root using GLS estimation of the deterministic component. Lag length is chosen using Ng and Perron's (2000) modified AI criteria. Test regressions include a constant and no trend. The notation *, ** and *** denotes significant at 10%, 5% and 1% significance level, respectively, using critical values taken from Cheung and Lai (1995) in *Stata* 11.

τ denotes the Engle-Granger test for the null hypothesis of no cointegration. This is the ADF test with lag order one on the residuals of the estimated cointegrating vector. Critical values are from MacKinnon (2010) using Schaffer's (2010) S*tata* code.

From a pure time series perspective, there is no reason to impose a $(1, -1)$ cointegrating vector between the productivity levels for each industry, which is in effect what the focus on the stationarity of z_t^* does. Also reported in Table 2.3 are tests for cointegration for unrestricted cointegrating vectors. For each industry, we report the Engle-Granger test statistic for the null hypothesis that the residuals are stationary. For all industries, we cannot reject the null hypotheses that the residual series have a unit root; in other words, we have no evidence of cointegration. There is no strong evidence of long-run relationships within industries across Canada and the US.[8]

2.4.2 Industry Short-Run Dynamics

With no long-run relationships evident in the data, we next consider the dynamic relationships using simple bivariate structural VAR models for each of the fifteen industries and manufacturing as a whole. As discussed previously, we specify a recursive ordering and examine the effects of orthogonalized US labour productivity shocks on the Canadian industry. For each industry, the lag order for the VAR is set to one, which is sufficient to ensure serially uncorrelated innovations.

The results for the bivariate VAR models are summarized in Figures 2.3 and Table 2.4. The figure reports the cumulative response of Canadian labour productivity in each industry to a standard deviation US labour productivity shock. Table 2.4 reports the size of the US productivity shock.

[8] We are acutely aware of the small sample of time series observations we have as well as the relatively short time span and recognize that this qualifies our conclusions here. We hope in future research to significantly expand the sample.

Figure 2.3 Response of Canadian Labour Productivity to One-S.D. US Labour Productivity Shock, by Industry and by Sector (65% CI)

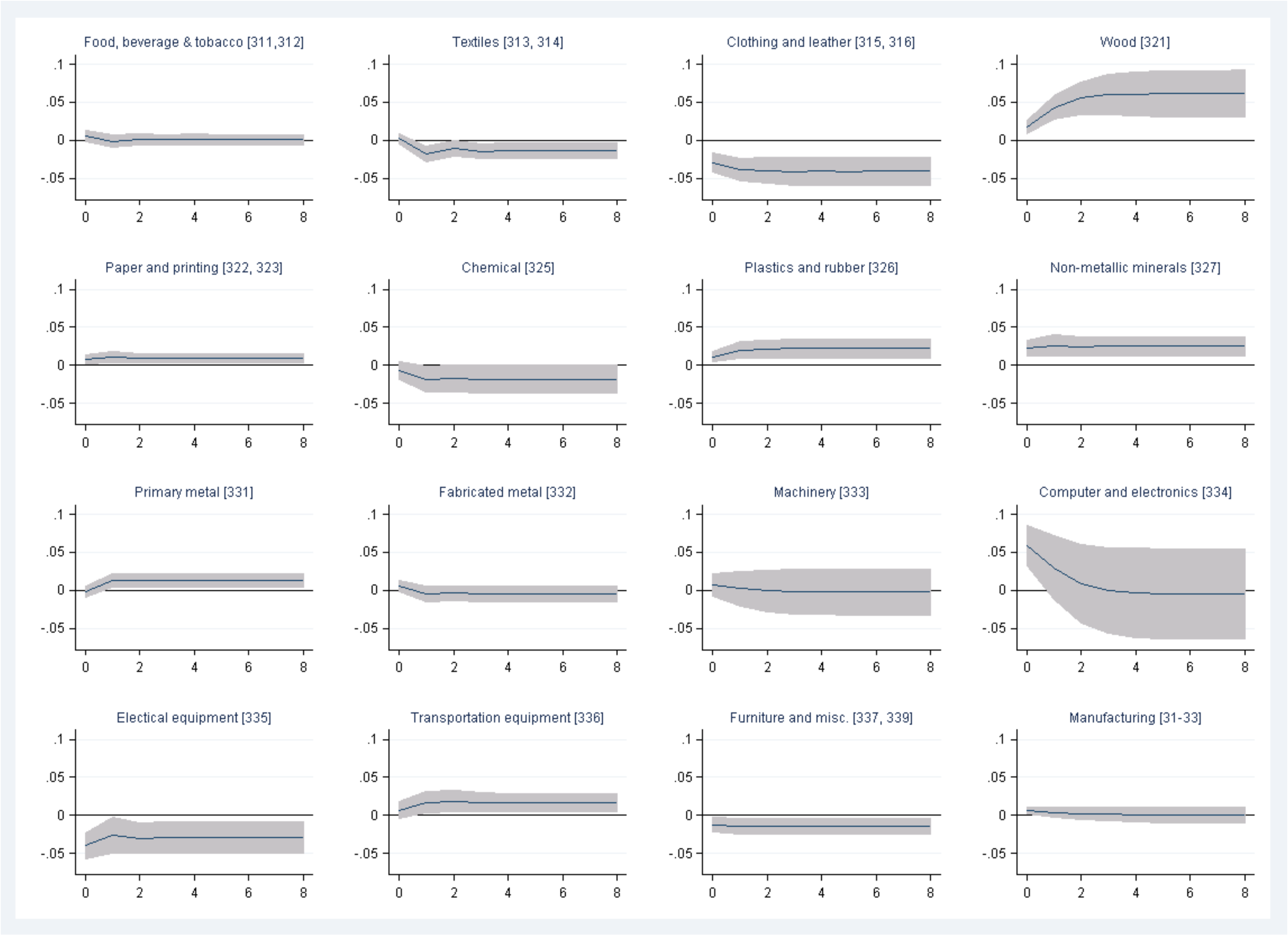


Table 2.4 Cumulated Impulse Response Functions and Forecast Error Variance Decompositions

NAICS Code	Description	US Shocks (s.e.)		Cum. Response (s.e.) Step 0		Cum. Response (s.e.) Step 8		FEVD Step 1	FEVD Step 8
311, 312	Food, beverage, and tobacco	0.048	(0.008)	0.005	(0.008)	0.001	(0.008)	0.021	0.050
313, 314	Textiles	0.081	(0.013)	0.002	(0.007)	-0.013	(0.011)	0.005	0.322
315, 316	Apparel and leather products	0.034	(0.006)	-0.029	(0.013)	-0.041	(0.020)	0.236	0.192
321	Wood products	0.066	(0.011)	0.018	(0.010)	0.061	(0.033)	0.162	0.405
322, 323	Paper and printing products	0.042	(0.007)	0.008	(0.006)	0.010	(0.006)	0.083	0.077
325	Chemical products	0.045	(0.007)	-0.007	(0.012)	-0.018	(0.020)	0.018	0.058
326	Plastics and rubber products	0.041	(0.007)	0.011	(0.007)	0.022	(0.014)	0.126	0.175
327	Non-metallic mineral products	0.058	(0.009)	0.023	(0.011)	0.025	(0.013)	0.210	0.212
331	Primary metal	0.068	(0.011)	-0.002	(0.008)	0.013	(0.009)	0.004	0.165
332	Fabricated metal	0.031	(0.005)	0.006	(0.008)	-0.004	(0.011)	0.024	0.104
333	Machinery	0.042	(0.007)	0.007	(0.016)	-0.002	(0.032)	0.011	0.017
334	Computer and electronic products	0.097	(0.016)	0.059	(0.028)	-0.005	(0.064)	0.208	0.250
335	Electrical equipment	0.070	(0.011)	-0.040	(0.018)	-0.029	(0.022)	0.234	0.256
336	Transportation equipment	0.039	(0.006)	0.007	(0.012)	0.017	(0.013)	0.018	0.053
337, 339	Furniture and miscellaneous	0.028	(0.005)	-0.012	(0.010)	-0.014	(0.011)	0.074	0.072
31-33	Manufacturing	0.020	(0.003)	0.007	(0.005)	0.000	(0.012)	0.091	0.107

Note: Shaded numbers are statistically significant using 65% confidence intervals reported in Figure 2.3.

In almost all cases, the bulk of the long-run effect, if any, occurs within two years, which seems a relatively quick pass through of productivity from the US to Canadian industries. Table 2.4 provides a simple summary of these effects, reporting the actual value of the one and eight year cumulative response.[9] Looking first at overall manufacturing, the initial impact of the US productivity shock is a 0.7 percent increase in Canadian labour productivity in response to a 2.0 percent increase in US labour productivity (one standard deviation shock). This effect is marginally significant initially but in the long run (eight years) the cumulative effect is zero. On the whole, variations in US labour productivity only have a short-run effect on Canadian labour productivity.

Three of the individual industries also exhibit no significant long-run effects, similar to aggregate manufacturing. These are (1) food, beverage, and tobacco; (2) fabricated metal; and (3) machinery. Indeed, in each of these cases not only is the long-run effect zero but so is the immediate impact of these shocks. There appears to be no significant connection between these industries either for the transfer or adoption of productivity methods or for competitive pressures to influence Canadian labour productivity.

Five of the individual industries experience significant permanent negative responses to US labour productivity shocks. These are (1) textiles; (2) clothing; (3) chemical products; (4) electrical equipment; and (5) furniture. In some instances, these are large effects: a 4.1 percent contraction for apparel and a 2.9 percent contraction for electrical equipment in response to one standard deviation US industry shocks. It is interesting to conjecture what might underlie these negative effects. One possibility is that as their US counterparts experience increases in productivity, these Canadian industries have become less competitive and have seen a fall in production. If this is coupled with slow labour adjustment (that is, Canadian firms are reluctant to shed labour) then Canadian labour productivity would fall. Note that this explanation is likely more relevant for the short run rather than the longer run. While it may be difficult to explain the negative effects (indeed, it may simply be a chance of correlation) the results for these industries certainly

[9] The figures also report 65% standard error bands.

suggest that there is no pressure on Canadian labour productivity from interactions with US industry.

For the remaining industries, seven in total, the effects are all positive on impact and for six of these positive in the long run as well. The seven industries are: (1) wood; (2) paper and printing; (3) plastics and rubber; (4) non-metallic minerals; (5) primary metals; (6) transportation equipment; and (7) computers and electronics. The last, computers and electronics, has only an initial positive impact and no long-run impact. Two industries in particular experience large effects: wood products and computers. In the case of the former, the long-run effect is in excess of 5 percent; for the latter, the impact effect is 5 percent, though falling to zero within two years. Overall, these sorts of responses are indicative of a significant amount of dependence Canadian and US industries, suggesting that Canadian firms in these industries respond to increases in labour productivity and subsequent competitive pressures arising south of the border.

We can also get an indication of the relative importance of US productivity shocks for Canadian labour productivity by examining the forecast error variance decomposition. These are also reported in Table 2.4, for both the one step and eight step ahead forecast. For brevity, we focus on the eight step horizon which is going to reasonably approximate the variance of Canadian labour productivity growth (see Hamilton, 1994). The industry with the largest US contribution is wood, just over 40 percent of the variation in Canadian labour productivity is coming from US productivity shocks; coupled with the impulse response functions we can now say that not only are the US effects large for this industry they are also an important source of shocks.

The next largest contribution of US shocks is to the textiles industry. Here we have the interesting result that the US shocks are important and contribute, somehow, to permanent declines in Canadian labour productivity in this industry. A similar result holds for electrical equipment and apparel, where US productivity shocks account for 20-25 percent of the variation in Canadian labour productivity.

Overall, the lesson from the forecast error variance decompositions is that US labour productivity shocks are a significant, though never the dominant, source of variation for a number of industries, suggesting that a better understanding of the means by which these productivity measures are related may be useful for a better understanding of Canadian labour productivity. Further, while US productivity shocks appear to be important, the direction of the effect is not uniform across industries. What follows is a preliminary attempt to determine what industry-specific features might contribute to these relationships.

2.4.3 Panel Analysis: Export, FDI and R&D Intensities

We estimate the dynamic panel model specified in equation (2.1) letting the w_i be: export intensity, foreign direct investment intensity, and research and development intensity. As noted previously, the model is estimated with industry-specific fixed effects and fixed time effects (that is, we include a dummy variable for each time period). For our model, we need to allow for differences in variance across panels since different industries are likely to have different scales in variation of growth rates. To do so, we use feasible GLS estimation allowing for heteroskedasticity across panels.[10]

We use Industry Canada's measure of Export Intensity as a measure of export orientation for an industry. This is constructed as domestic exports relative to industry revenue. As our focus is on the US we use domestic exports to the US. Domestic exports to the US refer to goods manufactured in Canada leaving for the US; it includes imported merchandise that has been 'substantially enhanced in value' (Industry Canada) and re-exported. (The measures are taken from Industry Canada's webpage.) For FDI, we construct a measure of intensity from the sum of inward and outward direct investment vis a vis the US for each industry, available from Statistics Canada CANSIM Table 376-0052. This is scaled by industry revenue. For R&D intensities, we use total business enterprise research and development intramural expenditures available from Statistics Canada CANSIM Table 358-0024, again scaled by industry revenue.

For all intensity measures, because we do not have complete time series over the full sample for each industry, we average over the time periods we do have. Averaging also has the advantage of smoothing out fluctuations in these measures. Arguably, the

[10] Standard tests for whether the variances are equivalent across panels are easily rejected.

contribution these characteristics will make to the transfer of labour productivity between the two countries depends on this broader description rather than year to year fluctuations in these measures. The intensity measures as used in estimation are reported in Appendix Table A2.1.

The estimated models are presented in Table 2.5. The first model, column (1), excludes the intensity variables and focuses only on the US labour productivity growth effects. For space considerations, we do not report the fixed industry and time effects nor do we report the industry specific lagged dependent variable. Briefly, the fixed effects are marginal and could in fact be dropped; doing so, however, has little effect so we do not do so. The time effects are jointly significant with a number of statistically significant individual years. Similarly, the lagged dependent variables are statistically significant more often than not and range in values from roughly −0.4 to 0.4. A test that the coefficients on the lagged dependent variables across industries are equal is easily rejected.

For model (1), the coefficients on current and lagged US productivity growth are jointly significantly different from zero, though individually only the current value itself is significant at standard levels. The sum effect of the two, however, is insignificantly different from zero. This weak dependence upon US labour productivity growth is entirely consistent with the VAR approach above; the panel model is in effect averaging the response across all industries and as we saw with VAR model, responses across industries range from negative through to positive. At best we can say from this model is that there appears to be a small interdependence between industries in the two countries.

Table 2.5 Domestic Export Intensity Panel Regression Model

$$\Delta x_{it} = \beta_0 + \eta_1 \Delta x^*_{it} + \delta_1 w_i \Delta x^*_{it} + \eta_2 \Delta x^*_{it-1} + \delta_2 w_i \Delta x^*_{it-1} + \beta_{i3} \Delta x_{it-1} + \varepsilon_{it}$$

	None (1)	Export Intensity (2)	FDI Intensity (3)	R&D Intensity (4)
Δx^*_{it}	0.149	-0.007	0.178	0.140
	(0.047)	(0.137)	(0.078)	(0.055)
Δx^*_{it-1}	-0.053	-0.336	-0.064	0.036
	(0.049)	(0.132)	(0.082)	(0.057)
$\Delta x^*_{it} w_i$		0.317		
		(0.292)		
$\Delta x^*_{it-1} w_i$		0.632		
		(0.283)		
$\Delta x^*_{it} w_i$			-0.127	
			(0.306)	
$\Delta x^*_{it-1} w_i$			0.160	
			(0.322)	
$\Delta x^*_{it} w_i$				1.944
				(2.752)
$\Delta x^*_{it-1} w_i$				-6.206
				(2.939)
Constant	0.001	0.004	0.001	0.001
	(0.017)	(0.017)	(0.017)	(0.017)
H_0: $\eta_1 = \eta_2 = 0$				
$\chi^2(2)$	12.240	6.520	6.637	6.786
p-value	0.002	0.038	0.036	0.034
H_0: $\eta_1 + \eta_2 = 0$	0.097	-0.344	0.114	0.176
$\chi^2(1)$	1.808	2.886	0.873	4.716
p-value	0.179	0.089	0.350	0.030
H_0: $\delta_1 + \delta_2 = 0$		0.950	0.033	-4.262
$\chi^2(1)$		5.665	0.005	1.383
p-value		0.017	0.944	0.240
No. of Obs.	285	285	285	266
No. of Industries	15	15	15	14

Note: Each regression includes industry fixed effects, time effects, and an industry specific lagged dependent variable; coefficients not reported. Each model is estimated using GLS allowing for industry specific variances. Numbers in parentheses are standard errors. Numbers in shade denotes 10% significance level.

Column (2) amends the first model by including the interaction between US labour productivity growth and the industry export intensity variable. As in model (1), the coefficients on US labour productivity are jointly significant (*p*-value of 0.038). The combined effect, however, is now negative and statistically significant at the 10 percent level (*p*-value of 0.089). The interaction terms, though, are both positive with the lagged interaction term statistically significant at the 10 percent level. When we consider the sum effect of the two interaction term coefficients, the effect is positive and statistically significant. Evidently, export intensity plays a significant and positive contribution to facilitating the interdependence of labour productivity in Canada and the US.

Column (3) reports the results concerning foreign direct investment intensity. In contrast to the export intensity results, here we find no statistically significant role for FDI intensity. The two interaction terms are individually insignificant as is the sum of their two effects.[11] In other respects, the model closely resembles that in column (1), suggesting that the FDI interaction terms are irrelevant regressors (as opposed to being co-linear with the US productivity growth variables.)

Finally, column (4) reports the results for research and development intensity. The US productivity growth coefficients are similar to model (1) as with the FDI model. The contemporaneous interaction term is positive but statistically insignificant. Surprisingly, the lagged interaction term is negative and statistically significant. Note that the magnitude of the coefficients is much larger than the other intensity measures because R&D intensity measures are much smaller. If we look at the combined effect, however, while negative it is statistically insignificant (with a *p*-value of 0.24). It would appear that R&D intensity is associated with short-term lower growth rates in Canadian industries in response to US productivity growth, though in the longer term the effect is not significant.

[11] It is possible that FDI and the other intensities play a direct role in increasing labour productivity in Canada, which would be picked up by the fixed effects; in fact, as there is little evidence in support of the fixed effects this does not appear to be the case. In any event, our focus is specifically on whether intensities contribute to the interdependence across the border and not the industry growth rate.

In the discussion above, we have looked at both the individual coefficients as well as the sum effect of the two. The sum effect is interesting because it gets at the long run effect on labour productivity growth. With a lagged dependent variable, though, a proper measure of the longer run effect is a bit more complicated. It is worth considering these effects because they provide a more general measure of the role for industry characteristics in having productivity growth pass through into Canadian industry. Given the results in Table 2.5, we focus on the export intensity model since this gives us the strongest, cleanest set of results. We consider two long-run multipliers. The first is the effect on steady state labour productivity growth in Canada from a permanent change in US labour productivity growth (also in steady state). The second is the effect on steady state labour productivity growth in Canada evaluated at mean US labour productivity growth.

Let Δx_i and Δx_i^* denote Canadian and US labour steady state productivity growth. Our model, evaluated at steady state is (setting the disturbance term to zero):

$$\mathbf{\Delta} x_i = \beta_0 + \eta_1 \mathbf{\Delta} x_i^* + \delta_1 w_i \mathbf{\Delta} x_i^* + \eta_2 \mathbf{\Delta} x_i^* + \delta_2 w_i \mathbf{\Delta} x_i^* + \beta_{i3} \mathbf{\Delta} x_i$$

Then our first long-run multiplier is:

$$\frac{d\mathbf{\Delta} x_i}{d\mathbf{\Delta} x_i^*} = \frac{1}{1-\beta_{i3}} \left[\eta_1 + \eta_2 + (\delta_1 + \delta_2) w_i \right] \tag{2.2}$$

The second long-run multiplier is:

$$\frac{d\mathbf{\Delta} x_i}{d\mathbf{\Delta} w_i} = \frac{1}{1-\beta_{i3}} (\delta_1 + \delta_2) \mathbf{\Delta} x_i^* \tag{2.3}$$

Values for these multipliers as well as test statistics for the null that these are zero are presented in Table 2.6. The test statistics are based upon a delta approximation and, in the case of the second multiplier, conditional on the mean value of industry-specific growth in US labour productivity.

Table 2.6 Long-Run Multipliers for Domestic Export Intensity Model

NAICS Code	Description	Change in Export Intensity				Change in US Growth			
		Multiplier	$\chi^2(1)$	*p*-value	w_i	Multiplier	$\chi^2(1)$	*p*-value	$\overline{\Delta x_i^*}$
311, 312	Food, beverage, and tobacco	0.010	3.871	0.049	0.209	-0.127	1.091	0.296	0.012
313, 314	Textiles	0.040	4.736	0.030	0.312	-0.048	0.230	0.631	0.041
315, 316	Apparel and leather products	0.031	5.285	0.022	0.300	-0.044	0.348	0.555	0.043
321	Wood products	0.004	3.231	0.072	0.608	0.385	3.900	0.048	0.003
322, 323	Paper and printing products	0.007	5.092	0.024	0.558	0.126	5.097	0.024	0.011
325	Chemical products	0.030	4.361	0.037	0.467	0.121	1.753	0.186	0.026
326	Plastics and rubber products	0.031	4.395	0.036	0.448	0.087	1.154	0.283	0.031
327	Non-metallic mineral products	0.010	4.229	0.040	0.260	-0.096	0.697	0.404	0.010
331	Primary metal	0.010	4.860	0.027	0.594	0.153	5.425	0.020	0.015
332	Fabricated metal	0.009	5.217	0.022	0.259	-0.074	0.740	0.390	0.012
333	Machinery	0.022	4.263	0.039	0.708	0.419	5.349	0.021	0.018
334	Computer and electronic products	0.223	4.885	0.027	0.751	0.398	6.412	0.011	0.218
335	Electrical equipment	0.018	4.775	0.029	0.526	0.127	3.713	0.054	0.023
336	Transportation equipment	0.023	4.095	0.043	0.775	0.434	5.113	0.024	0.022
337, 339	Furniture and miscellaneous products	0.026	5.038	0.025	0.477	0.084	2.144	0.143	0.036

Note: Estimates are based upon the model in column (2) of Table 2.5. Multipliers are calculated as detailed in text. $\chi^2(1)$ denotes the test statistics for the null hypothesis that the multiplier coefficient is zero; inference is based upon a delta approximation and, in the case of the intensity multiplier, conditional on the mean value of industry specific growth in US labour productivity. Numbers in shade denotes 10% significance level.

The first set of columns report the long-run multiplier and associated information for a (permanent) change in export intensity. The general conclusion is that the long-run effects of an increase in export intensity are positive for all industries and statistically significant at the 10 percent level. (In fact, for all but one industry at the 5 percent level.) The reported numbers can be interpreted as follows. First, note that the productivity growth rates used in the estimation (log first differences) have not been scaled by 100. So, for example, a unit change in w_i in the textiles industries (second row) increases productivity growth in Canada by 0.04. So if growth was previously 0.01 it would be 0.05, or five percent per year. Of course, a unit change in w_i is not of direct interest. A more reasonable change would be 0.1. In this case, if the textiles industries as a whole were to increase their export intensity from 0.312 to 0.412, steady-sate growth in this industry would rise by 0.004. From Table 2.1, average growth in the textiles industries, over the sample is 0.014 (reported in the Table as 1.4 percent). This increase in trade intensity would raise that growth rate to 0.018 or 1.8 percent. This appears to be a consequential increase in steady-state growth, though still well below the average productivity growth rate in the US for this industry of 4.1 percent.

A number of other industries have similarly sized effects. One industry, however, stands out and that is computer and electronics with a multiplier of 0.223. In this case, an increase in export intensity of 0.10 would add over two percentage point to long-run productivity growth in Canada. With an historical average of 4.8 percent this would see growth rise to 6.8 percent. For most industries, and computer and electronics in particular, increased export intensity would appear to have significant effects for long-run productivity growth rates in Canada.

In contrast, the results for the effects of US productivity growth are not uniform across the industries; nor are the effects statistically significant. Using 10 percent as our cut off for statistical significance, however, we find that the only statistically significant effects are positive. So, overall, we can conclude that either US productivity growth has a positive long-run effect or none at all (conditional of course on this model).

In this case, the largest multiplier is the transportation equipment industries, at 0.434. (As with export intensity, the computers and electronics industries have a large multiplier as well at 0.398.) In this case, a suitable exercise is to consider the effect of a one percentage increase in steady state US productivity growth. In the case of transportation this is an increase from 0.02 to 0.03. Steady-state Canadian productivity growth would increase by a multiple of 0.434, which is 0.04. This is a large effect. One reason (in fact, the main reason) this arises is because of the very large export intensity for this industry (0.775). Because of this exposure, the effects of US growth are passed through strongly in our model (see equations (2.2)-(2.3) for multipliers).

2.5 Summary

Our empirical analysis examines the relationships between labour productivity for Canadian and US industries, with the objective of uncovering the extent of dependence of Canadian labour productivity on US counterparts. It is well known that Canadian industries lag US industries in productivity, both in levels as well as in growth rates. Our analysis is designed to see the extent of pass through of productivity on an industry basis as well as to see whether certain industry characteristics facilitate this pass through.

The first set of results considers a standard question in the productivity literature: is there any evidence of *convergence* between labour productivity levels in Canadian industries to levels in US industries. For the three-digit manufacturing industries we consider, there is no evidence of any such long-run relationship.

From this point, we take a purely empirical perspective and look at each industry in isolation asking to what extent we observe labour productivity shocks feeding through into higher Canadian labour productivity. The answer is surprisingly little for most industries, a result that surprised us. (Indeed, one might anticipate the productivity relationship to be swamped by business cycle correlations but this does not appear to be the case for most industries.) There are some exceptions, notably wood products, which is perhaps not surprising given its close interdependence with the US market through trade.

Precisely because industry characteristics such as openness to trade might facilitate the pass through of productivity from the US to Canada, we then consider a panel model allowing for industry characteristics to determine the extent of this pass through. Here we find that export intensity appears to be an important conduit for productivity. When we focus on longer run effects, we find that increased export intensity uniformly increases labour productivity in Canadian industries; moreover, long run increases in US productivity growth either raise Canadian productivity growth, and in some cases by substantial amounts, or at worst have no effect.

Appendix Tables

Table A2.1 Intensity Measures

NAICS Code	Description	Export Intensity	FDI Intensity	R&D Intensity
311, 312	Food, beverage, and tobacco	0.2086	0.1502	0.0016
313, 314	Textiles	0.3125	0.0603	0.0069
315, 316	Apparel and leather products	0.2997	0.0214	-
321	Wood products	0.6081	0.1031	0.0022
322, 323	Paper and printing products	0.5583	0.3331	0.0066
325	Chemical products	0.4674	0.3908	0.0254
326	Plastics and rubber products	0.4481	0.197	0.0053
327	Non-metallic mineral products	0.2604	0.4229	0.0042
331	Primary metal	0.5937	0.1749	0.0049
332	Fabricated metal	0.2594	0.1876	0.0047
333	Machinery	0.7083	0.1299	0.0161
334	Computer and electronic products	0.751	0.5511	0.0996
335	Electrical equipment	0.5263	0.5878	0.018
336	Transportation equipment	0.7749	0.1831	0.0074
337, 339	Furniture and miscellaneous products	0.4774	0.1153	0.0083

Note: See text for details.

Chapter 3 Total Factor Productivity Growth Estimation: Do Different Methodologies Matter?

3.1 Introduction

Productivity measures how efficiently inputs are translated into outputs. It is often defined as output per unit of input. Productivity growth is the single most important driver of an economy's health over the longer term. It is the key determinant of economic growth, improvements in living standards, quality of life, and competitiveness. Productivity gains are also important for workers, consumers, businesses and governments because they translate into real wage gains, lower prices, higher profits, and increased tax revenue. Productivity growth will become increasingly important to Canadians in the future due to the ageing of population, slower labour force growth, and increasing competition from emerging economies such as China and India.

The term "productivity" is commonly used to refer to labour productivity, which is commonly defined as output per hour worked. However, labour productivity is only a partial measure of production efficiency. A better indicator is total factor productivity (TFP), also called multi-factor productivity (MFP). TFP measures how efficiently all inputs are used in the production process.

TFP growth, or the Solow residual, is calculated as growth in real output minus the weighted sum of growth of labour and capital:

$$\Delta TFP_{it} = \Delta \ln Y_{it} - (\bar{v}_{it}^{L} \Delta \ln L_{it} + \bar{v}_{it}^{K} \Delta \ln K_{it}) \tag{3.1}$$

where for industry i at time t Y_{it} is real value added, L_{it} and K_{it} are labour and capital inputs respectively, and $\bar{v}_{it}^{L}$ and $\bar{v}_{it}^{K}$ are the two-period average labour and capital income shares of value added. The TFP equation implies that the growth in TFP in industry i is the difference in growth between the real value added in that industry and a composite of labour and capital, weighted by their cost ratios to value added.

TFP estimates typically take into account changes in the quality of the inputs, due to shifts in their composition. For example, labour input measures are adjusted to reflect the gender, age and education levels of workers. As a result, the quality changes are excluded from the TFP measure. Thus, TFP is primarily influenced by business innovation, management practices, allocation of productive resources, and economies of scale and scope. Unlike capital and labour, these factors are difficult to quantify and isolate in practice, and thus are reflected in the residual. This is true at the level of plant, firm, industry or country. In addition, mis-measurements of either labour or capital will also be included in TFP, the residual.

Labour productivity is more popular than TFP because it is more closely related to GDP per capita and easier to measure, interpret and update, thereby commonly used in international comparisons. Compared to labour productivity, TFP is much more difficult to measure and is difficult to keep up-to-date. For instance, it is much easier to measure the number of hours worked than to estimate labour services that are adjusted for the composition of workforce.

In this paper, we investigate whether alternative methodological assumptions matter for TFP growth estimates in Canada and the US, and if so, how they affect the estimates in the US relative to those in Canada. In particular, we go to great lengths and develop necessary datasets for three alternative methodologies, using the same raw data. Under those alternative methodologies we then estimate and compare TFP growth rates by industry and for the business sector for both Canada and the US.

The remainder of the paper is organized as follows. Section 3.2 highlights the difficulty in measuring TFP. Section 3.3 lays out the alternative assumptions and methodologies for checking the sensitivity of TFP growth estimates in the paper. Section 3.4 describes data development for the alternative TFP methodologies, followed by a discussion of the results in Section 3.5. Section 3.6 concludes.

3.2 Motivation

The difficulty of measuring TFP is highlighted by Tang, Rao and Li (2010) and the Symposium on the Measurement of MFP in Canada in the 2012 Fall issue of the

International Productivity Monitor (IPM). Tang *et al.* (2010) shows that official capital and TFP estimates are not completely comparable across countries due to official statistics agencies in different countries using substantially different asset depreciation rates in estimating capital stock.[12]

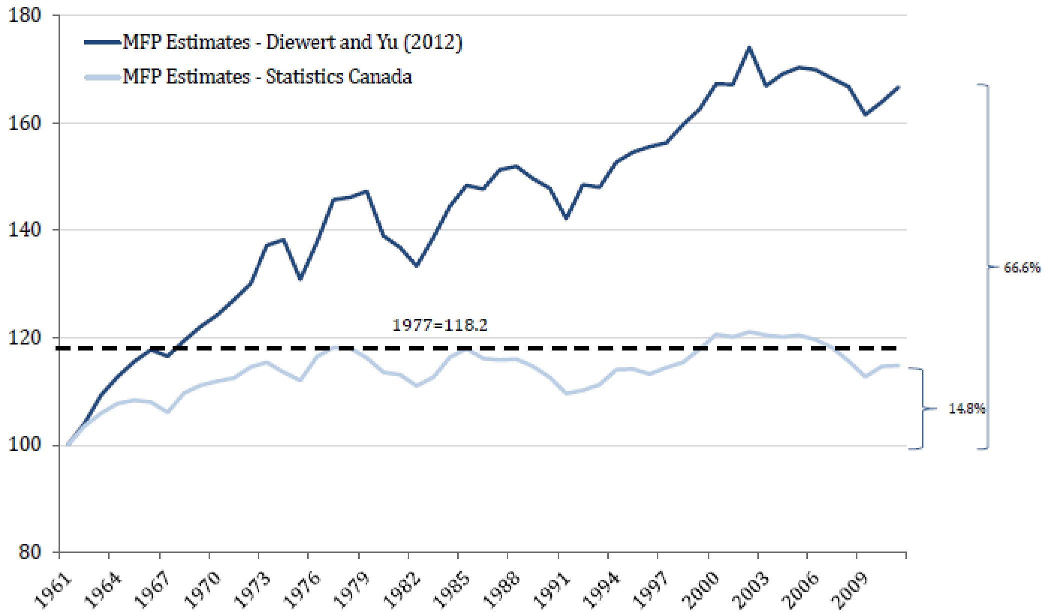
The IPM Symposium demonstrates that TFP estimates may also be sensitive to the choice of methodologies and the assumptions made in calculating TFP. In estimating TFP growth in the Canadian business sector, one needs first to estimate output and inputs (capital and labour) at the aggregate level. The Statistics Canada Productivity Program (CPP) assumes different real returns across capital assets and follows a bottom-up approach to aggregate each input from industry level. In contrast, Diewert and Yu (2012) assumes the same real return to different capital assets and follow the top-down approach by ignoring the industry dimension. As a result, the TFP growth rate estimates in Canada over the 1961-2011 period is estimated to have been 1.03 percent per year by Diewert and Yu and 0.28 percent per year by the CPP (Figure 3.1).

More specifically, the difference between the two TFP estimates is largely due to the difference in estimates of capital service inputs (Figure 3.2). Growth in capital service by the CPP is on average higher than that in Diewert and Yu by 1.8 percentage points per year from 1961-2011.

Capital service inputs are the sum of different capital stocks, weighted by their user costs. For each asset, user costs equal the nominal rate of return to the asset minus its price change, plus the depreciation rate and the rate of taxation on the asset. The nominal rate of return to the asset minus the price change for the asset is referred to as the real rate of return to the asset. The depreciation rate and the rate of taxation are pre-determined. Both Statistics Canada and Diewert and Yu calculate rates of return endogenously. That is, the sum of the user costs across all capital equals total capital compensation (i.e., nominal output minus labour compensation).

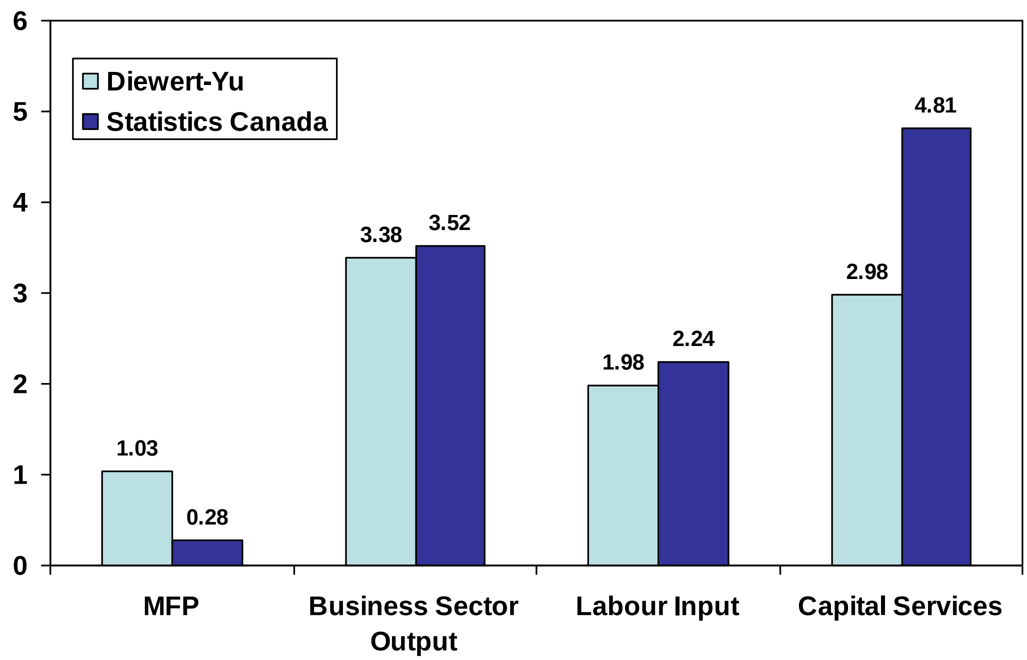
[12] Capital services are the weighted sum of different types of capital stocks, with weights being capital income shares of those capital stocks. The perpetual inventory method of estimating the capital stock suggests that capital stock and thus capital services are sensitive to the choice of asset depreciation rates, especially in level terms.

Figure 3.1 TFP Growth in Canada, Comparison between Diewert and Yu (2012) and Statistics Canada, 1961-2011 (Index, 1961=100)



Source: Diewert and Yu (2012)

Figure 3.2 TFP, Output and Input Growth in the Canadian Business Sector, 1961-2011 (Compound Annual Growth Rate, Percent)



Source: Diewert and Yu (2012)

Gu (2012) shows that the difference in the estimates of capital service inputs between the CPP and Diewert and Yu is mainly attributable to methodologies and assumptions made in estimating capital service inputs (Table 3.1). He demonstrates that three factors – bottom-up versus top-down approach, equal nominal versus equal real rates of return across assets, and 28 versus 14 reproducible assets – account for more than 90 percent of the difference in growth in capital service inputs. To a large extent, the difference in these three factors ultimately boils down to the difference in the estimates of real rate of return, in addition to the fact that underlying data used by the CPP and Diewert and Yu are different in many aspects.[13]

Table 3.1 Sources of Differences in Capital Input Growth between Diewert and Yu (2012) and the Canadian Productivity Program (Compound Annual Growth Rate, Percent)

	1961-2011	1961-1980	1980-2011
CAP minus Diewert and Yu (2012)	1.8	2.4	1.5
Accounted by:			
Bottom-up vs. top-down approach	0.8	1.2	0.6
Variable land vs. constant land	0.0	-0.1	0.1
Equal nominal vs. equal real rates of return across assets	0.5	0.7	0.3
28 vs. 14 reproducible assets	0.4	0.8	0.1
Unexplained	0.2	-0.2	0.4

Source: Gu (2012)

Following the bottom-up approach, the CPP first estimates capital service inputs, together with output and labour inputs, by industry (about 90 industries in total) and then aggregates over industries to business sector. The approach captures any variation in the rates of return across industries even for the same type of asset. Gu (2012) argues that the methodology employed by the CPP is also used by many countries, which improves comparability of Statistics Canada’s TFP estimates with those of others, particularly the

[13] For instance, investments in physical capital used by the CPP are benchmarked to input-output tables while they are not under Diewart and Yu. In addition, asset depreciation rates used by the CPP are constant while they are variable under Diewart and Yu. Finally, the land volume estimate for the CPP equals the dependable agriculture land for cultivation and urban land while it is assumed to be constant under Diewart and Yu.

US. In contrast, Diewert and Yu (2012) estimates capital service inputs only at business sector level, and implicitly assumes that rates of return do not vary across industries.

The second main difference relates to the assumptions made in calculating the real rate of return to asset, defined as nominal rate of return minus the rate of price change in asset. For each industry, the CPP calculates the real rate of return, assuming that the nominal rate of return for an asset is equal for all assets within an industry, and that the rate of price change in the asset can be approximated by the actual price change in investment. In contrast, Diewert and Yu believe that actual price change in investment is too volatile to be a proxy for the rate of price change in asset. They calculate the real rate of return, assuming that it is equal for all assets and for all industries (implicitly since industry dimension is ignored).

Thus, the difference in methodology in estimating capital service inputs between the CPP and Diewert and Yu boils down to their different ways in estimating the rate of return to capital. The former methodology allows for flexibility in the real rate of return, specific to asset and to industry, while the latter does not. Gu (2012) argues that growth in capital services by the CPP is higher because their approach controls for the shifts in composition of capital input. In particular, in addition to giving more weight to rapidly depreciating assets such as high-tech equipment (including computers, software and communications equipment) as in Diewert and Yu (2012), the CPP also gives more weight to those assets due to the substantial decline in their prices. As investment in high-tech equipment has become increasingly important over time, capital service estimates by the CPP have thus grown faster than those by Diewert and Yu (2012).

The debate highlights the methodological and measurement issues in estimating TFP. Unlike labour productivity, TFP estimates require that researchers and government statistical analysts adopt a methodology to develop capital service estimates. Alternative methodologies used to estimate capital service embody different assumptions for which there is no international standard. National statistical agencies employ different complex methodologies; even those who employ similar methodologies may choose among alternative assumptions, among other things, the quality of the underlying data and the preferred approach by agencies. Therefore, TFP estimates may vary.

3.3 Alternative methodologies

For the design of the alternative methodologies at the industry level and for the business sector, we follow closely the two alternative methodologies that are used by the CPP and by Diewert and Yu (2012). In addition, for Canada-US comparisons, we also consider both Statistics Canada and BEA asset depreciation rates, as Tang *et al.* (2010) shows that the choice of the depreciation rate may affect TFP estimates. Thus, at the industry level, the methodologies differ in the choice of asset depreciation rates and the assumption on the return to capital (Chart 3.1). For business sector, they also differ in aggregation approach - top-down versus bottom-up.

3.3.1 The Industry Level

At the industry level, we have four scenarios:

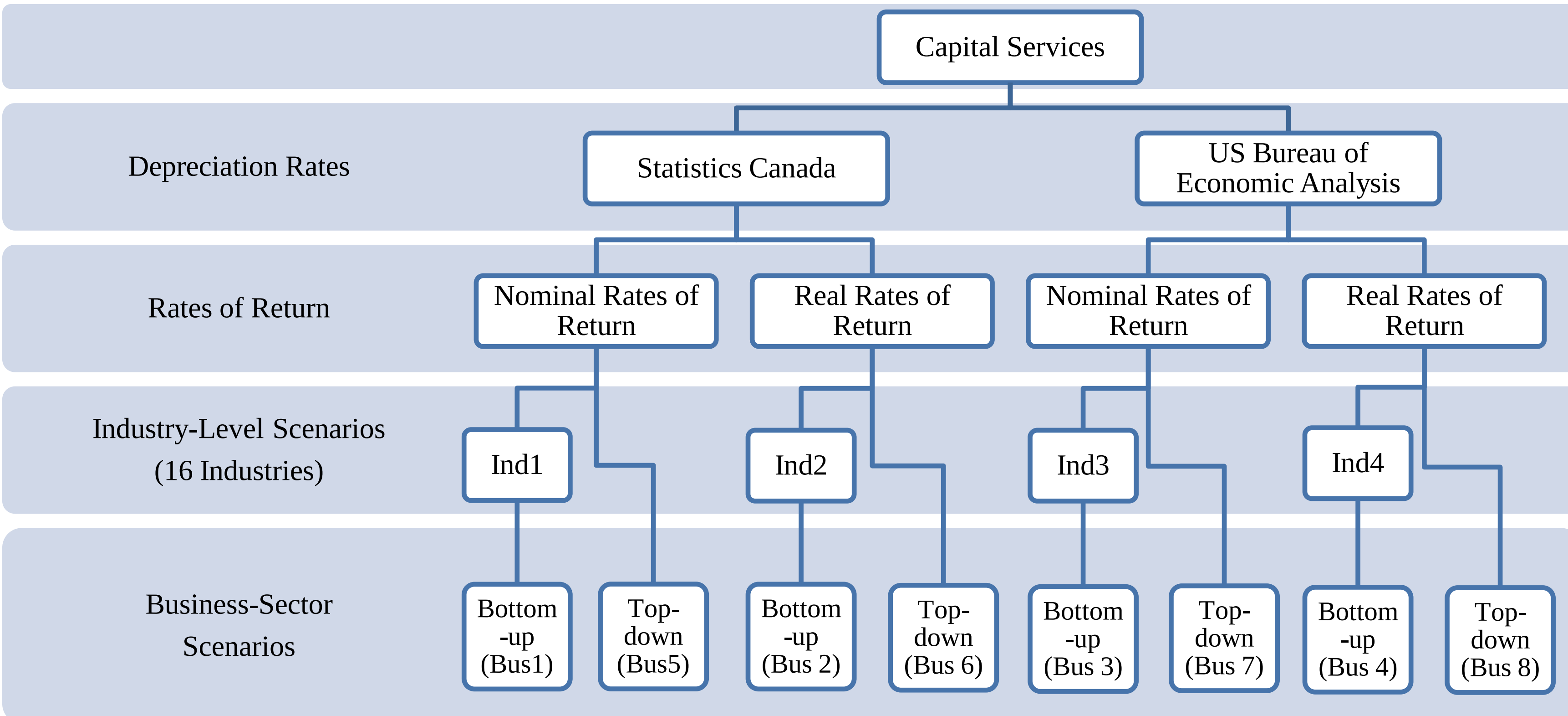
Ind1 Using *Statistics Canada asset depreciation rates* and assuming the *nominal* rate of return to capital are the same across asset types at the industry level

Ind2 Using *Statistics Canada asset depreciation rates* and assuming the *real* rate of return to capital are the same across asset types at the industry level

Ind3 Using *BEA asset depreciation rates* and assuming the *nominal* rate of return to capital are the same across asset types at the industry level

Ind4 Using *BEA asset depreciation rates* and assuming the *real* rate of return to capital are the same across asset types at the industry level

Chart 3.1 Alternative Capital Services Scenarios at the Industry and Business Sector Levels



Examples: Under scenario "Ind1", the capital service by two-digit NAICS industry classification (a total of sixteen industries) is derived from investment matrix with detailed asset and industry information (e.g., in Canada the matrix is by 175 asset types and 294 six-digit NAICS industries). The calculation utilizes Statistics Canada depreciation rates, assuming the nominal rates of return to capital to be identical across asset types within an industry. Subsequently, all sixteen "Ind1" capital services are aggregated into one - total capital service at the business sector, or scenario "Bus1".

Capital service under "Bus5" is derived from the same investment matrix using the same set of depreciation rates and assuming equal nominal rates of return to capital across assets. In contrast to "Bus1" capital service, "Bus5" aggregation does not involve industry aggregation. In other words, the nominal rate of return to an asset is identical across industries in the business sector.

Since output and labour service are the same, the differences in TFP estimates in these four scenarios depend entirely on how capital services are calculated. The use of Statistics Canada asset depreciation rates in general leads to lower levels of capital stocks and higher rates of return to capital compared to the use of BEA asset depreciation rates. The assumptions of the nominal and real rates of return to capital being the same across asset types, which are used respectively by the CPP and Diewert and Yu (2012), represent two "extremes". The former will generate the most volatile rates across different asset types while the latter, by definition, will produce the same rate of return to capital for all assets.[14]

3.3.2 The Business Sector

At the business sector level, each variable (GDP, labour services, or capital services) can also be constructed by either the bottom-up or the top-down approaches. As discussed earlier, using the bottom-up approach, each variable is aggregated over the same variable across industries. In contrast, using the top-down approach, the industry dimension is ignored and each variable is constructed directly at the aggregate level. Consequently, we present eight scenarios, indicated by Bus1, Bus2, …, and Bus8.

Bus1 Bottom-up from Ind1
Bus2 Bottom-up from Ind2
Bus3 Bottom-up from Ind3
Bus4 Bottom-up from Ind4

The first four scenarios for the business sector, Bus1-Bus4, are bottom-up-approach based. In other words, for these scenarios, each variable is aggregated over industries, corresponding to Ind1-Ind4. By design, the only difference among these four scenarios is in capital services.

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[14] Under the assumption of the nominal rate of return to capital being the same across all asset types, the rates of return to capital by industry for both Canada and the US are found to be positive, albeit volatile. To study of the impact of volatility on capital services estimates, we make no attempt to replace "outliers" by some external rate of return or by some industry average. The main purpose of calculating the rate of return to capital here is to allocate total capital compensation among different types of capital stock. The rate of return to capital, in addition to asset depreciation rates and the assumption on an equal nominal/real rate of return to capital, will also be influenced by other factors. For example, the rate of return will be lower when other types of capital such as land and inventory are included.

The remaining four scenarios, Bus5-Bus8, are top-down-approach based; that is, each variable is constructed at the aggregate level with no industry dimension being considered. Output and labour services do not vary across scenarios. Real output is aggregated over final demand categories. Labour services are the sum of hours worked by different types of labour, weighed by their labour compensation shares. Capital services, based upon different assumptions, are aggregated over different asset types at the business sector level. They vary across scenarios:

Bus5 Top-down, using *Statistics Canada asset depreciation rates* and assuming the *nominal* rate of return to capital are the same across asset types

Bus6 Top-down, using *Statistics Canada asset depreciation rates* and assuming the *real* rate of return to capital are the same across asset types

Bus7 Top-down, using *BEA asset depreciation rates* and assuming the *nominal* rate of return to capital are the same across asset types

Bus8 Top-down, using *BEA asset depreciation rates* and assuming the *real* rate of return to capital are the same across asset types

Scenario Bus1 is the method adopted by the CPP, while scenario Bus6 is the one employed by Diewert and Yu. The TFP growth estimates are, in general, different between the bottom-up and the top-down approaches. The top-down TFP represents the production possibility frontier (Jorgenson, Gollop and Fraumeni, 1987), assuming fully efficient input markets.[15] Compared to the bottom-up TFP, which is a weighted aggregate over industries with industry-specific input prices, the top-down TFP captures the effects of the reallocation of capital and labour inputs among industries (Jorgenson, 2012). If the reallocation effects are positive, then the top-down TFP will exceed the bottom-up one. This would be the case if industries with more rapid growth in inputs also pay relative high per-unit prices for these inputs.

The positive reallocation effect does not necessarily indicate an inefficient allocation of production resources. For example, a positive reallocation effect associated with capital may very well capture industry dynamics: some industries are growing faster and are

[15] In other words, input prices are the same across industries.

more profitable than others. This is because for all these alternative methodologies, capital compensation is the residual of nominal output minus labour compensation, and the rate of return to capital is endogenously determined. The positive reallocation effect reflects the process of resource being allocated to growing and more profitable industries.

3.4 Data Development

For our analysis, we develop comparable data for both Canada and the US for each scenario listed in the previous section. We start with industry grouping. For this study, the business sector is classified into sixteen broad industry groups which are at single or combined two-digit North America Industry Classification System (NAICS) level (Table 3.2). For the mining and manufacturing sectors, we further divide them, respectively, into two and sixteen industries at single or combined three-digit NAICS level. The classification is mainly driven by complying with Statistics Canada confidentiality constraints.

In Table 3.2, we report for both Canada and the US value added and hours worked shares of each industry in the business sector as an indicator of its relative importance in the two economies. Relative to the US, the Canadian business sector has higher employment and output shares in resource industries (such as mining, especially oil and gas extraction; wood products; primary metals; and food, beverage and tobacco products), construction, and transportation and warehousing. On the other hand, it has lower shares in computer and electronic products, chemicals, FIRE (finance, insurance and real estate, rental and leasing), and management of companies, and professional, scientific and technical services.

Table 3.2 Industry Classification and Industry Share of Nominal Value Added and Hours Worked, 2010

No.	Industry	NAICS Codes	Value Added (percent) CA	Value Added (percent) US	Hours worked (percent) CA	Hours worked (percent) US
1	**Agriculture, forestry, fishing, and hunting**	11	2.0	1.5	2.7	2.9
2	**Mining**	21	10.7	1.9	1.7	0.7
2.1	*Oil and gas extraction*	211	7.9	1.1	0.5	0.2
2.2	*Mining, except oil and gas*	212 & 213	2.7	0.8	1.2	0.6
3	**Utilities**	22	2.8	1.9	0.8	0.5
4	**Construction**	23	8.0	4.7	9.3	6.8
5	**Manufacturing**	321-339	12.9	15.3	11.2	11.4
5.1	*Wood products*	321	0.6	0.2	0.6	0.3
5.2	*Non-metallic mineral products*	327	0.4	0.3	0.4	0.4
5.3	*Primary metals*	331	1.0	0.4	0.5	0.4
5.4	*Fabricated metal products*	332	1.1	1.1	1.2	1.3
5.5	*Machinery*	333	1.0	1.3	0.9	1.0
5.6	*Computer and electronic products*	334	0.5	2.4	0.5	1.1
5.7	*Electrical equipment*	335	0.3	0.4	0.3	0.3
5.8	*Transportation equipment*	336	1.4	1.1	1.2	1.3
5.9	*Furniture and miscellaneous manufacturing*	337 & 339	0.7	1.1	1.0	0.9
5.1	*Food, beverage, and tobacco products*	311 & 312	2.3	1.6	1.8	1.6
5.11	*Textile mills and textile product mills*	313 & 314	0.1	0.1	0.1	0.2
5.12	*Apparel and leather and allied products*	315 & 316	0.1	0.1	0.3	0.1
5.13	*Paper products and printing*	322 & 323	1.1	0.8	1.0	0.9
5.14	*Petroleum and coal products*	324	0.5	1.6	0.2	0.1
5.15	*Chemical products*	325	1.0	2.1	0.7	0.8
5.16	*Plastics and rubber products*	326	0.6	0.6	0.7	0.6
6	**Wholesale trade**	41 or 42	6.1	5.9	5.7	5.2
7	**Retail trade**	44-45	6.7	6.7	11.3	11.7
8	**Transportation and warehousing**	48-49	5.1	3.5	5.6	4.1
9	**Information**	51	4.1	5.5	2.6	2.5
10	**FIRE* and management of companies**	52-53, 55	12.6	19.8	7.2	8.9
11	**Professional, scientific and technical services**	54	5.8	10.1	6.9	7.5
12	**Administrative and waste management**	56	2.9	3.9	5.0	6.9
13	**Education, health and social assistance**	61-62	13.7	11.6	15.8	16.6
14	**Arts, entertainment, and recreation**	71	1.1	1.2	2.0	1.5
15	**Accommodation and food services**	72	2.5	3.4	6.2	7.3
16	**Other services (except public admin)**	81	3.0	3.2	6.0	5.6
Business sector		11-81	100	100	100	100

* FIRE stands for Finance, Insurance, Real Estate, Rental and Leasing.

Source: Statistics Canada, the US Bureau of Economic Analysis (BEA) and the US Bureau of Labor Statistics (BLS).

In this paper, all Canadian industries include private and non-private activities (if applicable).[16] The "business sector" is total economy minus public administration and owner-occupied dwelling. Thus, our aggregate "business sector" differs from the traditional business sector that includes private activities only. Despite this departure, for simplicity, we continue to refer the aggregate as the business sector in this paper.[17]

3.4.1 Value Added

Data on industry value added in Canada are a special tabulation from Statistics Canada. It is consistent with CANSIM tables 379-0023 for value added in nominal dollars and 383-0021 for real value added. To ensure comparability with capital data, which will be discussed below, the value added data are adjusted to include both private and non-private activities (excluding government services). However, they exclude imputed rental income for owner-occupied housing. Moreover, to make it comparable to the US data, the original value added data at the basic prices are adjusted to value added at factor costs, using information on net indirect taxes on production from input-output tables from Statistics Canada.

The US data on industry value added are from the US Bureau of Economic Analysis (BEA). To make them comparable to Canadian data, two adjustments are made. First, the rental imputation for owner-occupied housing is excluded from real estate. Second, value added at market prices is adjusted to value added at factor costs, using information on both net indirect taxes on both products and production that are also from the BEA.

For the business sector, nominal GDP is the sum of industry nominal value added. Real GDP based on the bottom-up approach is aggregated over real value added at the industry level, using a Tornqvist index. Real GDP based on the top-down approach is derived from nominal GDP deflated by the top-down implicit GDP price deflator for the business sector. For Canada, the implicit GDP deflator for the business sector is from Statistics

[16] For instance, public portion of water treatment is included in utilities and public education and health are in education, health and social assistance. Note, however, that this paper excludes owner-occupied dwellings from FIRE and management of companies.

[17] For each of the listed scenarios, our database contains data on output (nominal and real); labour (hours worked, labour services, and labour compensation); and capital (investment, capital services and capital compensation for information and communication technology (ICT) machinery and equipment (M&E), non-ICT M&E, and structure).

Canada. Similarly, the implicit price deflator for the US business sector is from the BEA, which is also constructed based on final demand categories.

3.4.2 Labour Input

Productivity varies across individuals with gender, skill and age. Traditional measures of labour input, such as number of persons employed and number of hours worked, do not reflect these differences in nature. In contrast, labour service uses labour cost as weights to reflect the variation of labour types in productive contribution. It is hence a quality-adjusted measure.

Labour input is an index, which is aggregated over different types of labour using labour compensation as weights. It equals the product of hours worked and labour quality. To be consistent with output and other inputs, hours worked data for both Canada and the US are hours worked for all jobs, including both private and non-private activities. The hours worked data for Canada are special tabulation, which are consistent with CANSIM table 383-0009. For the US, they are from the Bureau of Labor Statistics (BLS), consistent with its prototype BEA/BLS Industry-level Production Account (Fleck *et al.*, 2012). To derive labour input estimates, the hours worked data are supplemented by data on labour quality constructed from detailed labour matrixes. The labour matrix by industry has three dimensions: gender (male and female), skill (low-, medium-, and high-skilled), and age (15-29, 30-49, and 50+).[18] For Canada, the labour matrix is from Statistics Canada, and for the US, it is from the EUKLEMS database, which is developed by Dale Jorgenson and his associates.

Labour matrix alone, when consistent, provides all information to construct labour service estimates. However, in this study the US data source for hours worked differs from that for labour quality. To ensure consistency of labour input index, we use labour quality derived from labour matrix as a proxy. That is, labour quality index is a ratio of labour service index to hours worked index, both of which are derived from the same labour matrix. For labour service index the paper follows Jorgenson, Gollop and

[18] Skill is based on education: high school graduate or less (low-skilled); post-secondary education or some university education (medium-skilled); and bachelors or higher (high-skilled).

Fraumeni (1987) and aggregate labour as a Tornqvist quantity index of individual labour types as

$$\Delta \ln L_{it} = \sum_{l} \bar{w}_{it}^{l} \Delta \ln H_{it}^{l}$$

where $\Delta \ln H_{it}^{l}$ denotes the growth of hours worked by labour type *l* and industry *i* at time *t*. Eighteen types of labour, as previously mentioned, are considered in total. The weight by labour type *l* in industry *i* at time *t* is given by two-period average shares in the value of labour compensation, i.e. $\bar{w}_{it}^{l} = (w_{it}^{l} + w_{it}^{l})/2$ and $w_{it}^{l} = (\sum_{l} p_{it}^{l} H_{it}^{l})^{-1} p_{it}^{l} H_{it}^{l}$ with $p_{it}^{l} H_{it}^{l}$ being the compensation of labour type *l*. The weights take into account the changing composition of labour force. Assume that marginal revenue equals marginal costs. The above equation ensures that the growth in hours worked from a labour type with higher compensation translates into a greater weight.

For US labour service, since the labour matrix is not comparable directly with the rest data structure labour service is calculated as a product of labour quality and hours worked. Labour quality is derived from labour matrix from the EUKLEMS database from 1987-2005 and is extended to 2010 using labour quality index from the BLS.[19]

3.4.3 Capital Services

Capital services measures the services from using capital stock. Similar to labour service, capital service accounts for productive contribution. It is an index that is aggregated over different types of asset using capital compensation as weights:[20]

$$\Delta \ln K_{it} = \sum_{a} \bar{w}_{it}^{a} \Delta \ln Z_{it}^{a}$$

[19] Labour service, derived from the labour matrix in EUKLEMS database, is only up to 2005; the coverage of the series is not comparable with the rest data. Labour quality, however, can be derived from this series by dividing it by the hours worked from the very same matrix. This labour quality provides a proxy for quality adjustment on hours worked from 1987-2005. It is extended to 2010 using BLS labour quality index, which is available from 1998-2010.

[20] Unlike the official estimates in Canada and the US, we exclude land and inventory, a practice used by the EUKLEMS program. Evidence for Canada indicates that TFP growth estimates will be slightly larger (about 0.1 percentage points higher) when land and inventory are included. This is because land and inventory are slowing moving assets.

where $\Delta \ln Z_{it}^{a}$ denotes the growth of capital stock by asset type *a* and industry *i* at time *t*. Twenty-seven types of comparable asset are considered in total. The weight for asset type *a* in industry *i* at time *t* is given by two-period average shares in the value of capital compensation, i.e. $\bar{w}_{it}^{a} = (w_{it}^{a} + w_{it}^{a})/2$ and $w_{it}^{a} = (\sum_{a} p_{it}^{a} Z_{it}^{a})^{-1} p_{it}^{a} Z_{it}^{a}$ where $p_{it}^{a} Z_{it}^{a}$ is the compensation of asset type *a*, and p_{it}^{a} is user cost of capital. The weights again take into account the changing asset composition.

The investment data used in generating non-residential capital stock estimates in Canada are based on investment surveys, conducted by the Investment and Capital Stock Division (ICSD) at Statistics Canada. These data are based on the NAICS and contain investment in current dollars as well as chained Fisher volume indices over 1961 to 2010 for 175 assets. The investment data for estimating non-residential capital stock in the US are from the BEA.[21] These data contain investment at the NAICS industry level for 74 assets over the period of 1901-2010.

Industry and Asset Aggregation

Complying with Statistics Canada confidentiality constraints, the study develops capital stock for Canada and the US by sixteen three-digit NAICS within manufacturing industries.[22] To simplify our analysis, the study categorizes various assets into 27 common types, to which the depreciation rates can be directly applied (see left panel in Table 3.3). These 27 types are then aggregated into four, including information and communication technology (ICT) machinery and equipment (M&E), non-ICT M&E, building structures, and engineering structures, which are further aggregated into M&E and structures. Finally, these two types are aggregated into total capital stock.

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[21] http://www.bea.gov/national/FA2004/Details/Index.html

[22] Originally Canadian manufacturing includes 21 three-digit NAICS industries while US manufacturing includes 19 four-digit NACIS industries. For comparison purposes, the study aggregates them into the common sixteen three-digit NAICS industries.

Table 3.3 BEA and Statistics Canada (Productivity Accounts) Depreciation Rates by Asset Type

Asset Code	Statistics Canada Asset Classification	Depreciation Rate: Implicit BEA	Depreciation Rate: Statistics Canada	Asset Class
1	Office furniture, furnishing (e.g. desks, chairs)	0.28	0.24	Non-ICT
2	Non-Office furniture, furnishings & fixtures (e.g. recreational equip.etc)	0.14	0.21	Non-ICT
3	Motors, Generators, and Transformers	0.11	0.13	Non-ICT
4	Computer-assisted process	0.13	0.17	Non-ICT
5	Non-computer-assisted process	0.11	0.16	Non-ICT
6	Communication Equipment	0.13	0.22	ICT
7	Tractors and Heavy Construction Equipment	0.17	0.17	Non-ICT
8	Computers, Associated Hardware & Word Processors	0.41	0.47	ICT
9	Trucks, Vans, Truck Tractors, Truck Trailers & Major Replacement Parts	0.19	0.23	Non-ICT
10	Automobiles and Major Replacement Parts	0.26	0.28	Non-ICT
11	Other Machinery and Equipment	0.13	0.20	Non-ICT
12	Electrical Equipment and Scientific devices	0.18	0.22	Non-ICT
13	Other Transportation Equipment	0.09	0.10	Non-ICT
14	Software	0.56	0.55	ICT
15	Plants for Manufacturing	0.03	0.09	Bldg
16	Farm Building, Maintenance Garages, and Warehouses	0.02	0.08	Bldg
17	Office buildings	0.02	0.06	Bldg
18	Shopping Centers and Accommodations	0.03	0.07	Bldg
19	Passenger Terminals, Warehouses	0.03	0.07	Bldg
20	Other Buildings	0.03	0.06	Bldg
21	Institutional Building Construction	0.02	0.06	Bldg
22	Transportation Engineering Construction	0.02	0.07	Eng
23	Electric Power Engineering Construction	0.02	0.06	Eng
24	Communication Engineering Construction	0.03	0.12	Eng
25	Downstream Oil and Gas Engineering Facilities	0.04	0.07	Eng
26	Upstream Oil and Gas Engineering Facilities	0.05	0.13	Eng
27	Other Engineering Construction	0.02	0.08	Eng
Simple Average				
ICTs		0.37	0.41	
Non-ICTs		0.15	0.19	
Building Construction		0.03	0.07	
Engineering Construction		0.03	0.09	
Total Assets		0.12	0.16	

Sources: Statistics Canada for Canada and authors' calculations based on BEA data for the US.

Capital Stock

Capital stock is calculated using the perpetual inventory method (PIM):

$$Z_{it}^{a} = Z_{it-1}^{a}(1-\delta^{a}) + I_{it}^{a}$$

where Z_{it}^{a} is the capital stock by industry *i* and asset type *a* at time *t*, I_{it}^{a} is the real investment in Fisher-chained 2002 dollars, and δ^{a} is the depreciation rate for asset *a*.

The real investment in Canada is estimated as a ratio of the nominal investment to price index:

$$I_{it}^{a} = NI_{it}^{a} / PI_{it}^{a}$$

where NI_{it}^{a} is the investment in current dollars, or nominal investment, while PI_{it}^{a} is the Fisher price index of investment with base year of 2002.

By contrast, BEA investment is benchmarked to 2005. For the purpose of bilateral comparison the study first rebases the investment to 2002:

$$I_{it}^{a} = \frac{IFQI_{it}^{a}}{IFQI_{i2002}^{a}} NI_{i2002}^{a}$$

where $IFQI_{it}^{a}$ is the Fisher-chained quantity index for investment with a base year of 2005.

Depreciation Rates and Initial Capital Stock

For this study, the rates for Canada are from Gellatly, Tanguay amd Yan (2002) for a diverse set of assets. The implicit BEA rates are derived from real investment and real capital stock. The study first aggregates across 63 four-digit NAICS industries in the US manufacturing. Rewriting PIM equation gives rise to a path of depreciation rate:

$$\delta_{t}^{a} = (Z_{it-1}^{a} - Z_{it}^{a} + I_{it}^{a}) / Z_{it-1}^{a}$$

By taking a simple average over the observed period the implicit BEA depreciation rate for asset *a* can then be written as: [23]

$$\delta^a = \frac{1}{t}\sum_t \delta_t^a$$

To apply the PIM, the study estimates Canadian capital stock using the historical investment from 1961-2010 with initial capital stock estimated as:

$$Z_0^a = \frac{I_0^a}{g^a + \delta^a}$$

where I_0^a is the real investment in asset *a* in the first year, or 1961 in the sample. δ^a and g^a are the depreciation rate and the average growth rate, respectively, from 1961-1981. For the US, capital stock is estimated using the historical investment from 1901 to 2010 with initial capital stock set to zero in 1901. The actual value chosen has little effect on capital stock estimates for the period of 1961-2010.

The PIM of estimating capital stock suggests that the estimate of capital stock is sensitive to depreciation rate. Before 2006, Statistics Canada more or less followed the BEA and produced Canada's capital stock estimates under the geometric depreciation profile. The estimates were thus fairly comparable to the BEA capital stock estimates. Since November 2006, however, Statistics Canada has followed the new depreciation rates estimated by Statistics Canada (2007).[24] Basically, under the new geometric depreciation profile, the declining balance rates are significantly larger and the services lives are significantly shorter than the ones used by BEA. As a result, the new depreciation rates are generally higher than the old rates, especially for structures.

[23] A few exceptions are applied in practice. First, a previous BEA depreciation rate is carried forward in the case of missing observations and/or negative rates. Second, rather than averaging over the entire observable period the depreciation rates are discarded at earlier periods to eliminate large outlier effect. Third, for aggregated asset types a weighted average is complied to discount fast depreciating asset of small size.

[24] That study is based on a Canadian micro database on the purchase and disposal of capital goods from Statistics Canada's Capital Expenditure Survey, which consists of data on the selling value of used assets, the age of the assets and the corresponding gross book value as well as the expected service lives of new assets. For other research on this topic, see Gellatly, Tanguay, and Yan (2002) and Patry (2007).

Because of the substantial difference in depreciation rates between Canada and the US, the official capital stock estimates, especially in terms of levels, are not comparable between the two countries. To resolve this problem, this paper uses either Statistics Canada or BEA depreciation rates to estimate capital stock for both Canada and the US.

The right panel of Table 3.3 reports Statistics Canada's new depreciation rates and the implicit BEA depreciation rates for 27 Canadian assets. The resulting new Canadian depreciation rates are on average higher than those used by the BEA for information communication technology (ICT) equipments (41 per cent vs. 37 per cent), non-ICT M&E (19 per cent vs. 15 per cent), building construction (7 per cent vs. 3 per cent), and engineering construction (9 per cent vs. 3 per cent).

Fisher-Type Chained Quantity

To estimate the Fisher-type chained quantity of investment and capital stock, the study utilizes three sets of matrices; investment/capital stock matrices in current price; investment/capital stock matrices evaluated at the prices in previous year (Lasypeyres prices), and investment/capital stock matrices evaluated at the prices in subsequent year (Paasche prices).

The nominal capital stock, denoted as PZ_{it}^{A}, at a more aggregated level, A (e.g., four types, including ICT, non-ICT, buildings and engineering) is aggregated from less aggregated asset types (e.g., the common 27 types), where $a \in A$.[25]

$$PZ_{it}^{A} = \sum_{i,a} PZ_{it}^{a}$$

The Fisher-chained quantity index of capital stock is estimated as a geometric mean of the Laspeyres and Paasche index:

[25] The industry aggregation is analogous to asset aggregation. The nominal capital stock in asset A for manufacturing sector (*MANU*) at time t, PZ_{MANUt}^{A} $_t$, equals the sum of capital stock of all individual industry i, where $a \in MANU$. That is, $PZ_{MANUt}^{A} = \sum_{i} PZ_{it}^{A}$.

$$\frac{IFQZ_{it}^{A}}{IFQZ_{it-1}^{A}} = (\frac{ILQZ_{it}^{A}}{ILQZ_{it-1}^{A}} \cdot \frac{IPQZ_{it}^{A}}{IPQZ_{it-1}^{A}})^{\frac{1}{2}}$$

where the Laspeyres quantity index of capital stock, $\frac{ILQZ_{it}^{A}}{ILQZ_{it-1}^{A}}$, uses the previous year's investment prices to aggregate capital stock for industry *i* and more aggregated asset type *A* while the Paasche quantity index of capital stock, $\frac{IPQZ_{it}^{A}}{IPQZ_{it-1}^{A}}$, uses current-year investment prices to aggregate capital stock:

$$\frac{ILQZ_{it}^{A}}{ILQZ_{it-1}^{A}} = \frac{\sum_{a} P_{it-1}^{a} Z_{it}^{a}}{\sum_{a} P_{it-1}^{a} Z_{it-1}^{a}}$$

$$\frac{IPQZ_{it}^{A}}{IPQZ_{it-1}^{A}} = \frac{\sum_{a} P_{it}^{a} Z_{it}^{a}}{\sum_{a} P_{it}^{a} Z_{it-1}^{a}}$$

where Z_{it}^{a} is the Fisher-chained quantity of capital stock of industry *i* in asset *a* and P_{it}^{a} is the 2002 chained price index of investment which is provided along with the investment data by the ICSD, Statistics Canada. Since 2002 is the base year for the Fisher-chained quantity index, the real capital stock in Fisher-chained 2002 dollars can then be expressed as follows:

$$Z_{it}^{a} = \frac{IFQZ_{it}^{A}}{IFQZ_{i2002}^{A}} \times PZ_{i2002}^{A}$$

The Fisher-chained price index of capital stock can be derived as a ratio of the nominal capital stock to the real capital stock in Fisher-chained 2002 dollar:

$$IFPZ_{it}^{A} = PZ_{it}^{A} / Z_{it}^{A}$$

User Cost of Capital

As its name suggests, user cost of capital is the cost of using capital. Following the EUKLEMS program, we define it as[26]

$$p_{it}^{a} = \left(r_{it}^{a} - \rho_{it}^{a} + \delta_{it}^{a} \right) P_{it}^{a}$$

where for capital (asset) *a* in industry *i* at time *t*, r_{it}^{a} is the nominal rate of return to capital *a*; ρ_{it}^{a} is the rate of price change in asset *a*; δ_{it}^{a} is the depreciation; and P_{it}^{a} is the investment price of asset *a*.

There are different ways of estimating user cost of capital. In this chapter, we follow two different approaches, currently adopted by the CPP at Statistics Canada and Diewert and Yu (2012), to test the sensitivity of TFP estimates to alternative methodologies. For both methods, the rate of return to capital is determined endogenously. That is, the sum of capital stock multiplied by user cost over all types of assets equals total capital compensation. The depreciation rate of an asset and the investment price of the asset are pre-determined. The nominal rate of return to capital and the rate of price change in asset have to be estimated.

Statistics Canada assumes that the rate of price change in asset can be approximated by the actual ex-post rate of price change in an asset. Assuming the nominal rate of return to capital to be the same for all assets within an industry, and the total user cost of capital to be equal to the actual ex-post total capital compensation of the industry, the CPP calculates the nominal rate of return to capital endogenously for the industry.

In contrast, Diewert and Yu (2012) believes that the actual ex-post rate of price change in asset is not a good proxy for the rate of price change in an asset because it is too volatile.

[26] In this chapter, following the practice by EUKLEMS (http://www.euklems.net/) for estimating user cost of capital for international comparisons, we exclude the tax parameter, which is different from Statistics Canada's TFP program and Diewert and Yu (2012). There are three reasons for the exclusion. First, we don't have comparable data on tax for the US. Second, our capital compensation is at factor cost, excluding tax on production and products. Finally, it is not an important factor for user cost of capital since capital service estimates without the tax parameter are very similar to those estimates with the tax parameter, based on a calculation using the CPP data.

Consequently, they assume that real rate of return to capital, which equals the nominal rate of return to capital minus the rate of price change in asset, is equal across all assets and all industries. They then calculate endogenously the real rate of return to capital, assuming as in the CPP, that the sum of total user cost of capital is equal to the actual ex-post total capital compensation for the business sector.

3.5 Discussion

In this section, we compare and contrast TFP growth estimates based on different methodologies, with a focus on the implication of TFP growth trend in Canada and the Canada-US TFP growth gap.

3.5.1 TFP Growth by Industry

At the industry level, there are four scenarios for each country, corresponding to combinations of the two sets of asset depreciation rates (Statistics Canada or BEA) and two rate-of-return assumptions (equal nominal or real rate of return to capital across all assets). Thus the four scenarios differ only in estimation of capital services, with other variables being the same.

The capital services growth estimates under these four scenarios from 1987-2010 were in general similar, with the correlation coefficients being more than 0.964 for Canada and 0.983 for the US (Table 3.4). The largest difference was between the use of different asset depreciation rates with Statistics Canada depreciation rates being applied to Ind1 and Ind2 and BEA depreciation rates to Ind3 and Ind4. In contrast, the growth estimates in capital service based on the assumption of an equal nominal rate of return to capital across all assets were very close to those based on the assumption of an equal real rate of return to capital (Ind1 vs. Ind2 and Ind3 vs. Ind4).

Table 3.4 Growth in Capital Services by Industry in Canada and the US, 1987-2010 (Average Annual Growth Rate, Percent)

	Canada				US			
	Ind1	**Ind2**	**Ind3**	**Ind4**	**Ind1**	**Ind2**	**Ind3**	**Ind4**
Agriculture, forestry, fishing, and hunting	-1.1	-1.2	-0.5	-0.5	0.6	0.6	0.6	0.6
Mining	4.4	4.4	4.5	4.4	0.8	0.8	0.9	0.9
Oil and gas extraction	4.8	4.8	4.9	4.8	0.8	1.0	1.0	1.1
Mining, except oil and gas, and support activities	2.6	2.5	2.7	2.5	0.5	0.4	0.5	0.4
Utilities	1.3	1.2	1.6	1.5	1.4	1.2	1.7	1.6
Construction	4.1	4.0	4.1	4.0	4.2	4.1	4.3	4.2
Manufacturing	1.3	1.2	1.7	1.6	2.0	1.9	2.2	2.0
Wood products	1.1	1.1	1.8	1.6	-0.6	-0.7	0.0	-0.2
Non-metallic mineral products	1.4	1.3	1.3	1.2	0.6	0.5	0.6	0.5
Primary metals	-0.7	-0.8	0.2	0.2	-0.2	-0.4	-0.3	-0.4
Fabricated metal products	1.1	1.1	1.4	1.4	1.0	1.0	1.3	1.2
Machinery	2.2	2.1	2.4	2.3	1.9	1.8	2.3	2.2
Computer and electronic products	1.3	1.2	2.2	2.1	4.6	4.3	5.0	4.7
Electrical equipment, appliances, and components	0.9	0.8	1.3	1.3	-0.4	-0.4	0.6	0.5
Motor vehicles, bodies and trailers, and others	2.0	1.9	2.9	2.7	2.4	2.2	2.7	2.5
Furniture and related products, and miscellaneous	3.3	3.2	3.5	3.4	1.9	1.8	2.1	2.0
Food, beverage, and tobacco products	1.1	1.0	1.1	1.0	1.1	1.1	1.4	1.3
Textile mills and textile product mills	-2.1	-2.2	-1.1	-1.0	-2.8	-2.9	-1.4	-1.5
Apparel and leather and allied products	-1.6	-1.7	-0.6	-0.6	-1.6	-1.7	-0.4	-0.4
Paper products, printing and related support activities	-0.9	-1.0	0.1	0.0	-0.4	-0.5	0.4	0.3
Petroleum and coal products	4.2	3.4	4.3	3.5	2.8	2.7	2.1	2.0
Chemical products	-0.5	-0.5	0.3	0.3	2.4	2.3	2.6	2.5
Plastics and rubber products	2.5	2.4	2.9	2.8	1.8	1.8	2.2	2.2
Wholesale trade	6.5	6.4	5.8	5.6	3.2	3.1	3.6	3.4
Retail trade	6.2	6.0	5.7	5.5	4.0	3.8	4.2	4.0
Transportation and warehousing	3.8	3.6	3.4	3.1	1.8	1.5	1.5	1.0
Information	4.9	4.8	5.1	4.9	5.6	5.1	5.8	5.5
FIRE, Management of companies and enterprises	4.0	3.7	4.5	4.2	3.9	3.7	4.5	4.3
Professional, scientific, and technical services	13.9	13.7	13.7	13.4	8.8	8.6	8.3	8.2
Administrative and waste management	7.4	7.2	4.7	4.4	5.5	5.3	5.7	5.5
Education and Health care and social assistance	4.2	4.0	3.4	3.1	5.1	4.9	5.0	4.8
Arts, entertainment, and recreation	6.3	6.0	6.5	6.2	5.4	5.4	4.8	4.7
Accommodation and food services	3.2	3.1	3.7	3.6	2.2	2.2	2.4	2.4
Other services (except public admin)	5.4	5.1	3.0	2.6	2.6	2.5	2.6	2.5
Correlations by Approach								
Ind1: StatCan depreciation, equal nominal rate of return	1.000	0.999	0.971	0.964	1.000	0.999	0.985	0.984
Ind2: StatCan depreciation, equal real rate of return		1.000	0.972	0.967		1.000	0.983	0.984
Ind3: BEA depreciation, equal nominal rate of return			1.000	0.998			1.000	0.999
Ind4: BEA depreciation, equal real rate of return				1.000				1.000

Because of the similar growth estimates in capital services, the TFP estimates by industry from 1987-2010 in the four scenarios were also similar for most industries (Table 3.5).[27] Interestingly, similar patterns in capital service emerge for both countries. The estimates under Ind1 were almost identical to those under Ind2, and Ind3 estimates were almost identical to those under Ind4, with the correlation coefficients being almost one for both Canada and the US. This, in turn, suggests that TFP growth estimates are not sensitive to different assumptions on the rate of return to capital. The pattern seems to hold in general for the 1987-2000 and 2000-2010 sub-periods.[28]

In addition, the difference in TFP growth rate between Canada and the US is found to be fairly similar across the four scenarios for most industries, with the correlation coefficients being almost one between any two scenarios of the four (Table 3.6)

These results suggest that the TFP growth estimates are fairly robust to different choices of asset depreciation rates, and especially to different assumptions on the rate of return to capital.[29]

3.5.2 TFP Growth in Business Sector

In addition to the choice of asset depreciation rates and the assumption on the rate of return to capital, we can also choose between the bottom-up and the top- down approach at the business sector level. As discussed in the previous section, we have eight different scenarios.

[27] For labour productivity growth by industry for 1987-2000, 2000-2010 and 1987-2010, see Table A3.1 in Appendix.

[28] TFP growth rate estimates for the two sub-periods are reported in Tables A3.2 and A3.3 in Appendix.

[29] The finding on different asset depreciation rates is also consistent with Tang, Rao and Li (2010) showing TFP estimates being generally similar when the two different sets of asset depreciation rates are used to estimate capital stock.

Table 3.5 TFP Growth by Industry in Canada and the US, 1987-2010 (Average Annual Growth Rate, Percent)

	Canada				US			
	Ind1	**Ind2**	**Ind3**	**Ind4**	**Ind1**	**Ind2**	**Ind3**	**Ind4**
Agriculture, forestry, fishing, and hunting	3.1	3.1	2.7	2.7	2.1	2.1	2.1	2.1
Mining	-2.1	-2.1	-2.1	-2.1	-0.7	-0.7	-0.7	-0.7
Oil and gas extraction	-2.5	-2.5	-2.5	-2.5	-2.7	-2.8	-2.7	-2.8
Mining, except oil and gas, and support activities	-1.0	-0.9	-1.0	-0.9	1.1	1.2	1.2	1.2
Utilities	-0.1	0.0	-0.3	-0.2	-0.3	-0.2	-0.5	-0.4
Construction	-0.8	-0.7	-0.8	-0.7	-2.2	-2.2	-2.2	-2.2
Manufacturing	1.2	1.2	1.0	1.0	2.6	2.7	2.6	2.6
Wood products	2.1	2.1	1.9	1.9	0.5	0.5	0.5	0.5
Non-metallic mineral products	0.1	0.2	0.2	0.3	0.0	0.1	0.1	0.1
Primary metals	3.0	3.0	2.7	2.7	0.7	0.7	0.8	0.8
Fabricated metal products	0.3	0.3	0.2	0.2	0.0	0.1	0.0	0.0
Machinery	1.0	1.0	0.9	0.9	1.1	1.1	1.0	1.0
Computer and electronic products	2.8	2.9	2.7	2.7	19.6	19.7	19.5	19.6
Electrical equipment, appliances, and components	-0.2	-0.2	-0.3	-0.2	0.8	0.9	0.5	0.5
Motor vehicles, bodies and trailers, and others	1.9	1.9	1.6	1.6	-0.3	-0.3	-0.4	-0.3
Furniture and related products, and miscellaneous	0.2	0.3	0.2	0.2	3.3	3.3	3.2	3.2
Food, beverage, and tobacco products	0.3	0.3	0.3	0.3	0.0	0.0	-0.2	-0.1
Textile mills and textile product mills	0.4	0.4	0.1	0.1	3.3	3.3	2.9	2.9
Apparel and leather and allied products	0.5	0.5	0.3	0.3	3.6	3.6	3.3	3.3
Paper products, printing and related support activities	0.9	0.9	0.6	0.6	0.7	0.7	0.5	0.5
Petroleum and coal products	-1.4	-1.1	-1.4	-0.9	3.3	3.4	3.9	4.0
Chemical products	1.6	1.6	1.2	1.2	-0.3	-0.3	-0.4	-0.4
Plastics and rubber products	1.0	1.0	0.9	0.9	1.6	1.6	1.4	1.4
Wholesale trade	1.2	1.2	1.4	1.4	2.5	2.5	2.4	2.4
Retail trade	1.7	1.7	1.7	1.8	2.0	2.0	1.9	2.0
Transportation and warehousing	0.0	0.0	0.1	0.2	1.5	1.6	1.7	1.8
Information	0.5	0.6	0.4	0.5	1.9	2.1	1.7	1.9
FIRE, Management of companies and enterprises	0.2	0.3	-0.1	0.1	-0.2	-0.1	-0.6	-0.5
Professional, scientific, and technical services	-1.5	-1.5	-1.5	-1.4	-1.1	-1.0	-0.9	-0.9
Administrative and waste management	0.0	0.0	0.5	0.6	0.7	0.7	0.6	0.7
Education and Health care and social assistance	-1.5	-1.5	-1.4	-1.3	-1.7	-1.7	-1.7	-1.7
Arts, entertainment, and recreation	-1.7	-1.6	-1.8	-1.7	-0.5	-0.4	-0.2	-0.2
Accommodation and food services	0.0	0.0	-0.1	-0.1	0.4	0.4	0.3	0.3
Other services (except public admin)	-1.1	-1.1	-0.8	-0.7	-1.3	-1.3	-1.3	-1.3
Correlations by Approach								
Ind1: StatCan depreciation, equal nominal rate of return	1.000	0.999	0.991	0.989	1.000	1.000	0.999	0.999
Ind2: StatCan depreciation, equal real rate of return		1.000	0.990	0.990		1.000	0.999	0.999
Ind3: BEA depreciation, equal nominal rate of return			1.000	0.998			1.000	1.000
Ind4: BEA depreciation, equal real rate of return				1.000				1.000

Table 3.6 TFP Growth Difference by Industry in Canada and the US, 1987-2010 (Percentage Points)

	Diff (US-Canada)			
	Ind1	**Ind2**	**Ind3**	**Ind4**
Agriculture, forestry, fishing, and hunting	-0.9	-0.9	-0.6	-0.6
Mining	1.5	1.4	1.5	1.4
Oil and gas extraction	-0.2	-0.3	-0.2	-0.4
Mining, except oil and gas, and support activities	2.1	2.1	2.1	2.1
Utilities	-0.3	-0.2	-0.2	-0.2
Construction	-1.5	-1.5	-1.5	-1.5
Manufacturing	1.5	1.5	1.6	1.6
Wood products	-1.5	-1.5	-1.4	-1.4
Non-metallic mineral products	-0.1	-0.1	-0.2	-0.2
Primary metals	-2.3	-2.3	-1.9	-1.9
Fabricated metal products	-0.2	-0.2	-0.2	-0.2
Machinery	0.1	0.2	0.1	0.1
Computer and electronic products	16.8	16.8	16.8	16.8
Electrical equipment, appliances, and components	1.0	1.0	0.8	0.8
Motor vehicles, bodies and trailers, and others	-2.2	-2.2	-2.0	-2.0
Furniture and related products, and miscellaneous	3.0	3.0	2.9	3.0
Food, beverage, and tobacco products	-0.3	-0.3	-0.4	-0.4
Textile mills and textile product mills	2.9	2.9	2.8	2.8
Apparel and leather and allied products	3.1	3.1	3.0	3.0
Paper products, printing and related support activities	-0.2	-0.2	-0.1	-0.1
Petroleum and coal products	4.7	4.4	5.3	4.9
Chemical products	-1.9	-1.9	-1.6	-1.6
Plastics and rubber products	0.6	0.5	0.5	0.5
Wholesale trade	1.3	1.3	1.0	1.0
Retail trade	0.3	0.3	0.2	0.2
Transportation and warehousing	1.6	1.6	1.6	1.6
Information	1.4	1.5	1.3	1.4
FIRE, Management of companies and enterprises	-0.4	-0.4	-0.5	-0.5
Professional, scientific, and technical services	0.4	0.4	0.5	0.5
Administrative and waste management	0.7	0.7	0.1	0.1
Education and Health care and social assistance	-0.2	-0.2	-0.3	-0.3
Arts, entertainment, and recreation	1.2	1.2	1.6	1.5
Accommodation and food services	0.3	0.3	0.4	0.4
Other services (except public admin)	-0.2	-0.2	-0.5	-0.5
Correlations by Approach				
Ind1: StatCan depreciation, equal nominal rate of return	1.000	1.000	0.998	0.998
Ind2: StatCan depreciation, equal real rate of return		1.000	0.997	0.998
Ind3: BEA depreciation, equal nominal rate of return			1.000	1.000
Ind4: BEA depreciation, equal real rate of return				1.000

Real GDP based on the bottom-up approach was in general similar to that based on the top-down approach (Figure 3.3) for both Canada and the US. In Canada, real GDP based on the bottom-up and the top-down approaches grew almost at the same pace of 2.3 percent per year over the period of 1987-2010 (Table 3.7). In the US, real GDP based on the bottom-up approach grew 2.6 percent per year as opposed to 2.8 percent per year based on the top down approach. This small difference was mainly driven by the difference in 2000-2010. In this sub-period, real GDP based on the bottom-up approach grew at 1.4 percent per year as opposed to 1.7 percent per year based on the top-down approach.

Figure 3.3 Real GDP in the Canadian and US Business Sector (2002=100), 1987-2010

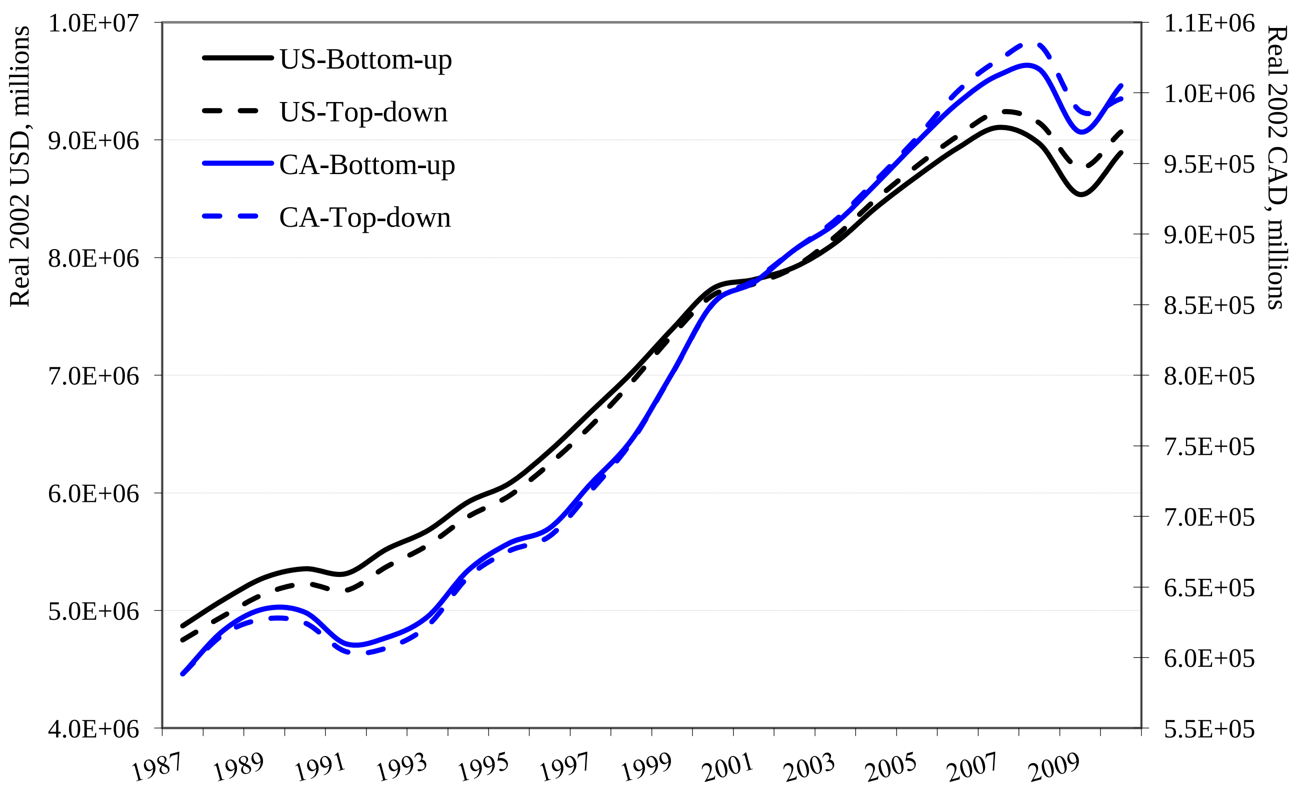
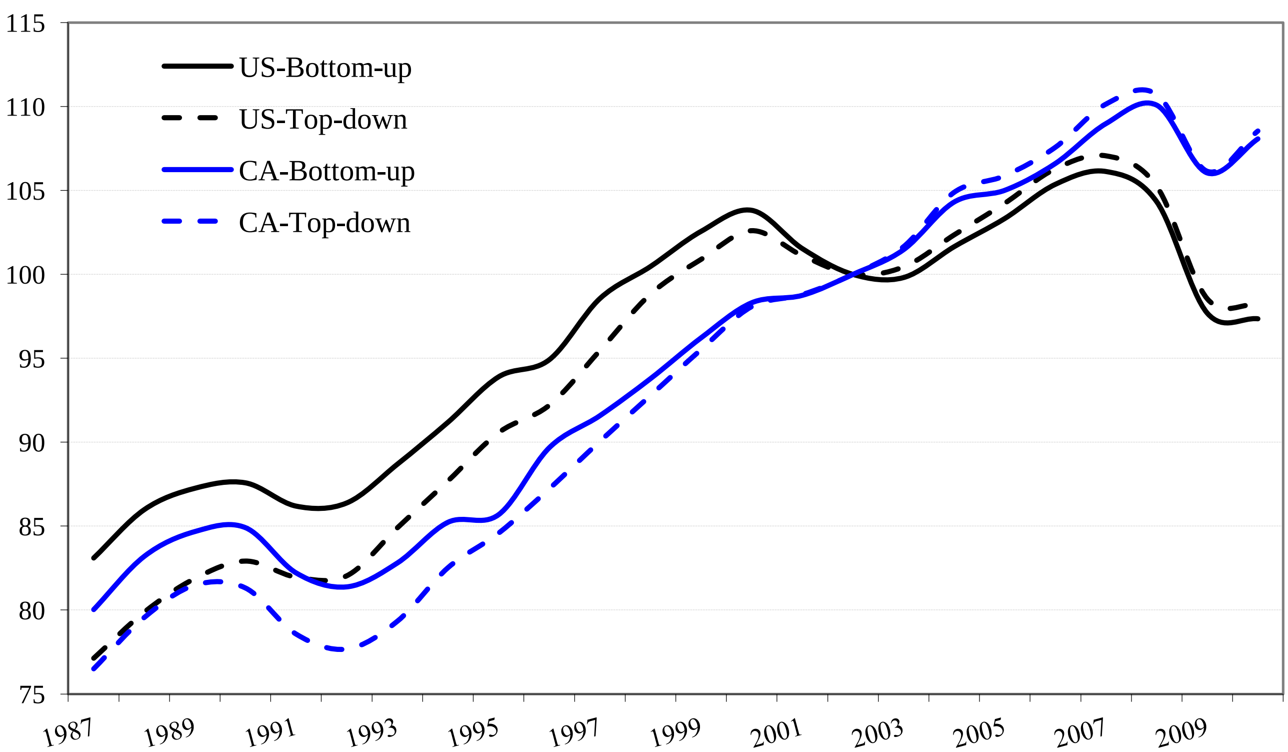


Table 3.7 TFP Growth in the Canadian and the US Business Sector (Average Annual Growth Rate, Percent)

	Canada			US		
	1987-2000	2000-2010	1987-2010	1987-2000	2000-2010	1987-2010
Bottom-up Approach						
Value Added	2.84	1.67	2.33	3.56	1.39	2.62
Labour Services	1.67	1.01	1.38	1.71	-0.64	0.69
***Bus1*: Bottom-up, StatCan asset depreciation rates, and equal nominal rate of return to capital**						
Capital Services	3.90	3.32	3.65	5.01	2.01	3.71
TFP	0.44	-0.19	0.17	0.60	1.03	0.78
***Bus2*: Bottom-up, StatCan asset depreciation rates, and equal real rate of return to capital**						
Capital Services	3.76	3.18	3.51	4.77	1.94	3.54
TFP	0.48	-0.14	0.21	0.69	1.05	0.85
***Bus3*: Bottom-up, BEA asset depreciation rates, and equal nominal rate of return to capital**						
Capital Services	3.93	3.43	3.71	5.06	2.43	3.92
TFP	0.43	-0.23	0.15	0.58	0.86	0.70
***Bus4*: Bottom-up, BEA asset depreciation rates, and real nominal rate of return to capital**						
Capital Services	3.77	3.25	3.54	4.80	2.36	3.74
TFP	0.49	-0.16	0.21	0.68	0.89	0.77
Top-down Approach						
Value Added	2.84	1.58	2.29	3.70	1.66	2.81
Labour Services	2.06	1.21	1.69	2.19	-0.44	1.05
***Bus5*: Top-down, StatCan asset depreciation rates, and equal nominal rate of return to capital**						
Capital Services	3.38	3.29	3.34	4.51	1.91	3.38
TFP	0.27	-0.42	-0.03	0.56	1.18	0.83
***Bus6*: Top-down, StatCan asset depreciation rates, and equal real rate of return to capital**						
Capital Services	3.20	3.17	3.19	4.29	1.81	3.21
TFP	0.32	-0.39	0.01	0.64	1.21	0.89
***Bus7*: Top-down, BEA asset depreciation rates, and equal nominal rate of return to capital**						
Capital Services	3.52	3.24	3.40	4.35	2.23	3.43
TFP	0.24	-0.40	-0.03	0.62	1.06	0.81
***Bus8*: Top-down, BEA asset depreciation rates, and equal real rate of return to capital**						
Capital Services	3.30	3.09	3.21	4.08	2.11	3.22
TFP	0.31	-0.35	0.02	0.71	1.10	0.88

The growth estimate for labour service was higher by the top-down approach than that by the bottom-up approach for both Canada and the US (Figure 3.4). Over the period 1987-2010, labour service by the top-down approach in Canada grew at 1.7 percent per year as opposed to 1.4 percent per year by the bottom-up approach - a difference of 0.3 percentage points per year (Table 3.7). For the US, labour service grew at 1.1 percent per year by the top-down approach and 0.7 percent per year by the bottom-up approach - a difference of 0.4 percentage points per year. Most of the difference appeared to be in the pre-2000 sub-period in both countries. The difference suggests that industries with relatively high growth in labour input paid relatively lower labour compensation (e.g., wages) than industries with relatively low labour growth. As labour compensation for the same type of worker is in general higher in the manufacturing sector than in the service sector, this result may reflect the long-term trend that the economies shift from the manufacturing sector to the service sector.

Figure 3.4 Labour Services in the Canadian and US Business Sector (2002=100), 1987-2010



Capital service estimates in the eight scenarios are summarized in Figures 3.5 and 3.6 for Canada and the US, respectively. In general, the largest difference was due to the choice of different approaches. Capital service grew faster by the bottom-up approach (in solid lines) than that by the top-down approach (in dash lines). For Canada, capital service based on the bottom-up approach grew at a rate between 3.5-3.7 percent per year in 1987-2010 while it grew at 3.2-3.4 percent per year by the top-down approach. For the US, it grew at 3.5-3.9 percent per year by the bottom-up approach is based and 3.2-3.4 percent per year by the top-down approach. This result is consistent with the finding of Diewert and Yu (2012) and Gu (2012) for Canada.[30] These findings suggest that in both countries, industries with faster growth in capital services also tend to maintain higher rates of return to capital, indicating that industries with high growth in capital input are likely to be more profitable.

As shown in Figure 3.7, ICT capital services in the eight scenarios were fairly close to one another, especially for Canada. The differences in total capital services among these scenarios were to a large extent caused by other capital assets, especially structures.

TFP growth is calculated as the residual of real GDP growth that cannot be explained by labour and capital input growth. The TFP growth estimates corresponding to these eight scenarios are reported in Figure 3.8 for Canada and in Figure 3.9 for the US.[31]

For Canada, the TFP estimates by the bottom-up approach (in solid lines) grew at a more rapid pace than those by the top-down approach (in dash lines). This is because, under the bottom-up approach, real GDP grew faster while labour services grew slower in the post-2000 period (Table 3.7).

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[30] However, our difference between different scenarios is much smaller compared to that between the CPP and Diewert and Yu (2012). In the period 1987-2010, capital services grew 3.7 percent per year according to the CPP and 2.2 percent per year according to Diewart and Yu, a different of 1.5 percentage points. In contrast, the difference in capital services growth between our scenarios is relatively smaller, as capital services for Canada grew at a range of 3.2-3.7 percent per year, depending on the scenarios. It is likely that the difference between the CPP and Diewart and Yu also reflect differences in underlying data.

[31] For labour productivity growth and its contributors in the business sector for 1987-2000, 2000-2010 and 1987-2010, see Table A3.4 for Canada and Table A3.5 for the US.

Figure 3.5 Capital Services in the Canadian Business Sector (2002=100), 1987-2010

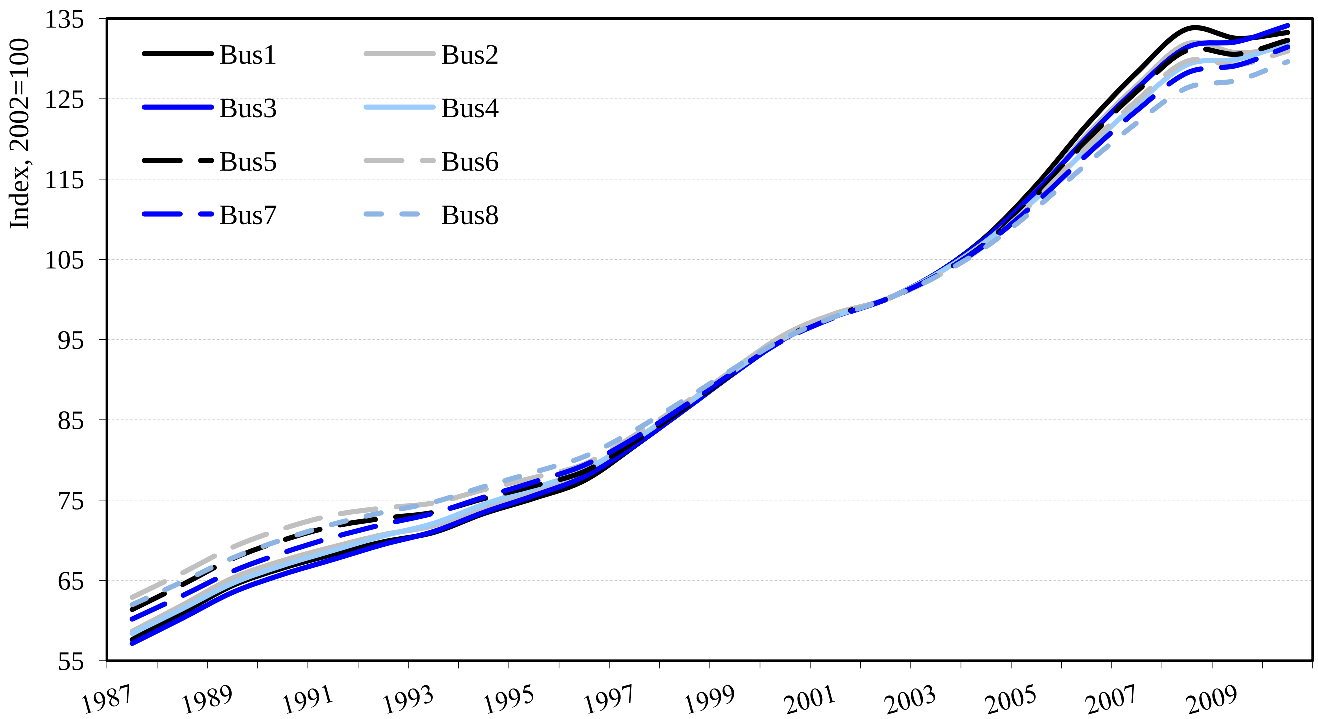


Figure 3.6 Capital Services in the US Business Sector (2002=100), 1987-2010

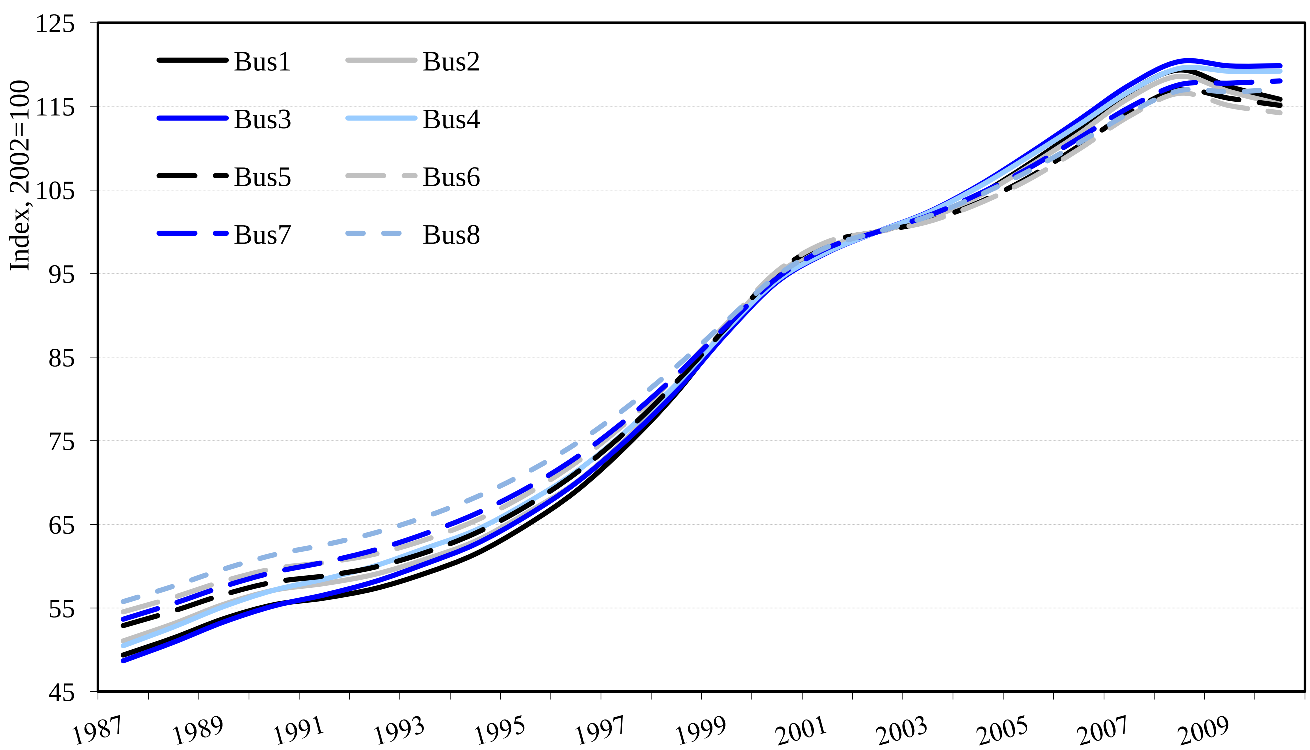


Figure 3.7 Various Capital Services in the Canadian and the US Business Sector (2002=100), 1987-2010

Canada	US

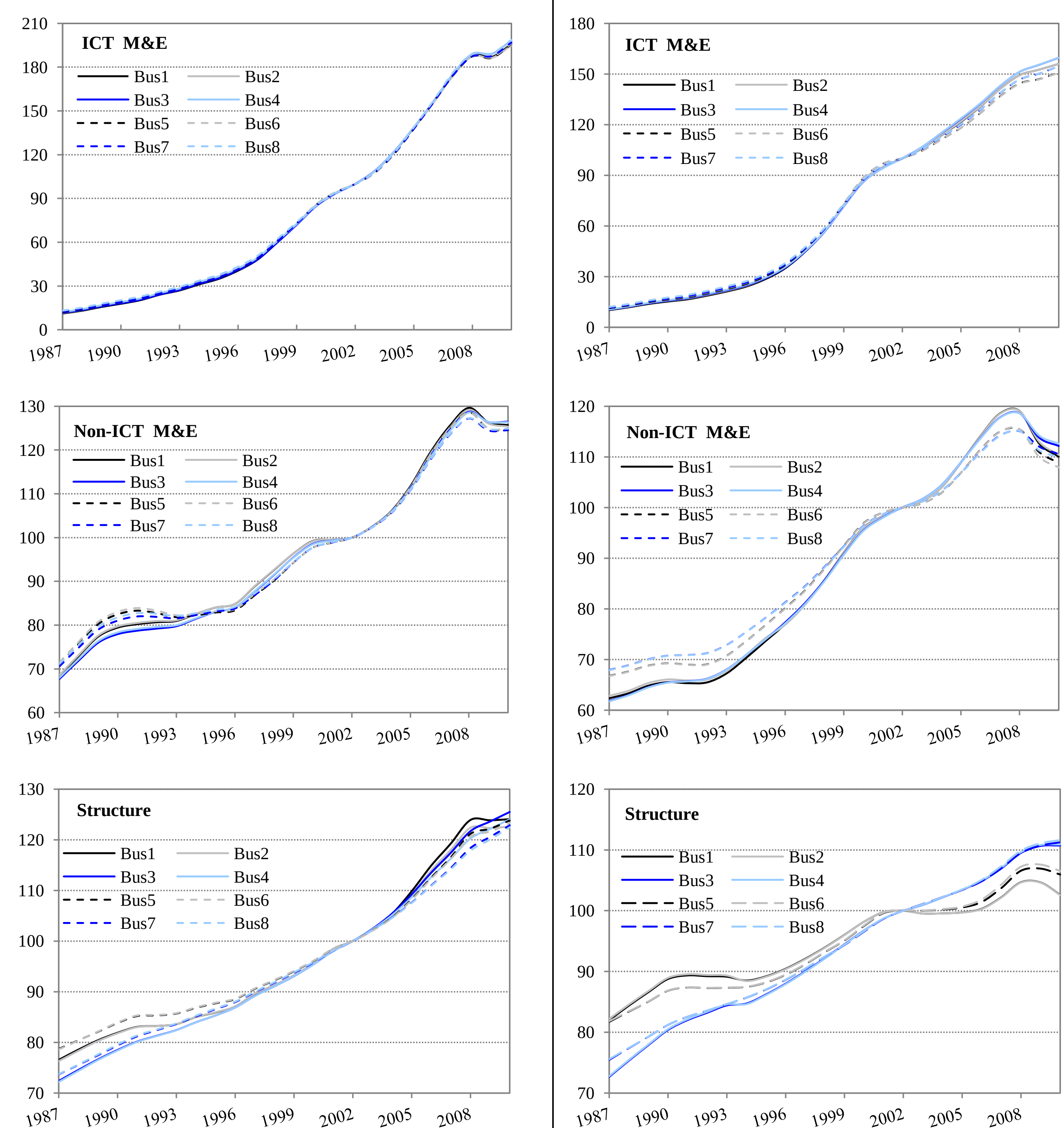


Figure 3.8 TFP in the Canadian Business Sector (2002=100), 1987-2010

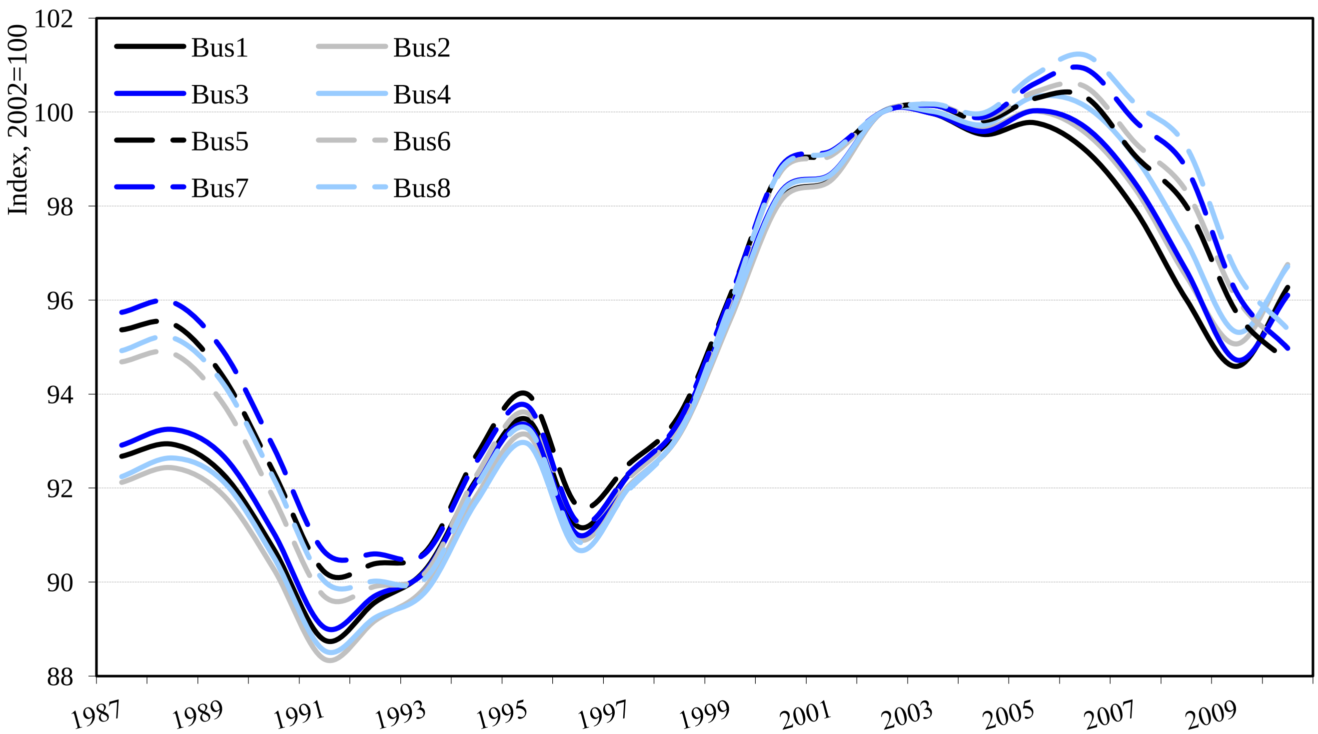
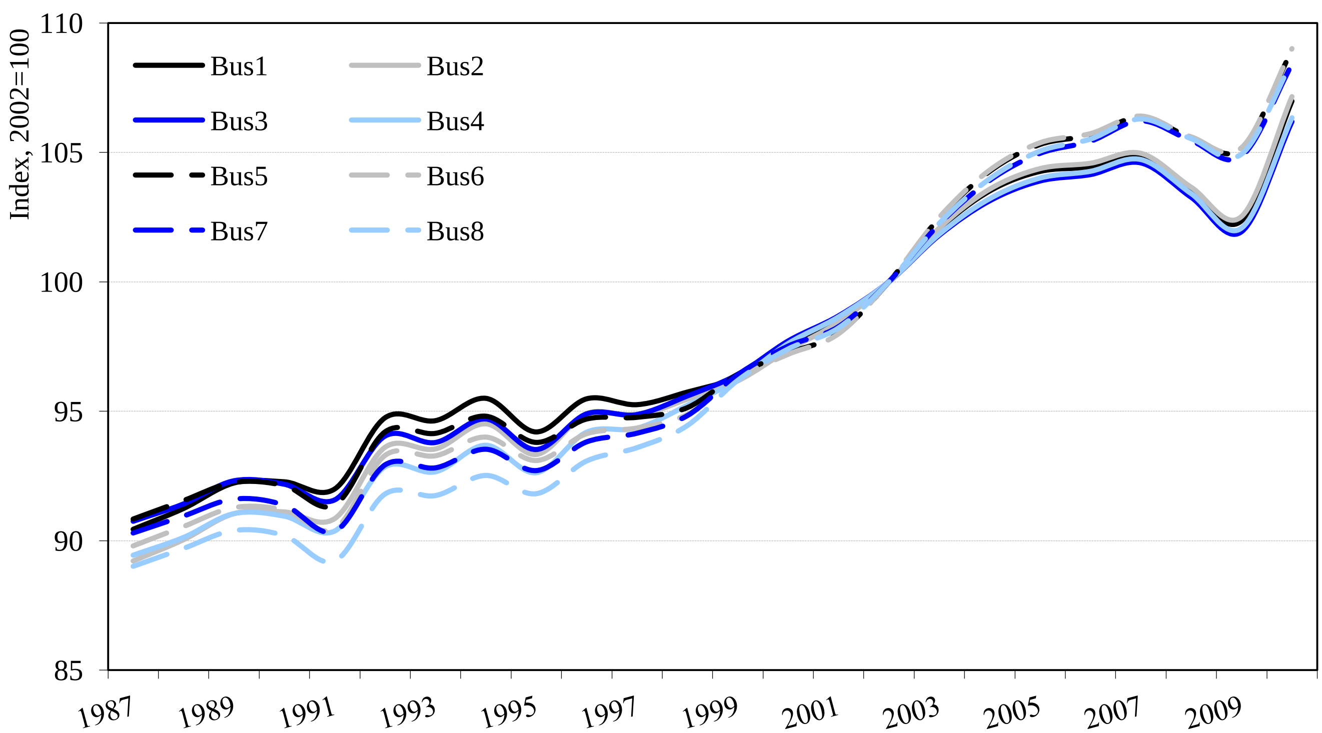


Figure 3.9 TFP in the US Business Sector (2002=100), 1987-2010



For the US, the opposite was true: the TFP estimates based on the bottom-up approach grew slower than those based on the top-down approach. Under the bottom-up approach, real GDP for the US grew slower while capital service grew faster (especially for the 1987-2000 period). The difference in TFP estimates between the two countries may reflect, in large part, the difference in industry structures and industry dynamics between the two countries.

By comparing Figure 3.8 to Figure 3.9 we observe a more volatile TFP growth in Canada than in the US. This may capture the fact that Canada, as a small open economy that concentrates in resource-based industries, is more sensitive to external shocks and volatile commodity prices.

Despite the differences across different scenarios, TFP growth estimates in the business sector were fairly robust to alternative assumptions and methodologies in 1987-2010 (Table 3.7). This is the case for both countries. For the Canadian business sector, the highest and the lowest TFP growth estimates were 0.21 and -0.03 per cent per year, respectively, with a difference of 0.24 percentage points. For the US business sector, the highest and the lowest TFP estimates were 0.89 and 0.70, per cent per year, respectively, with a difference of 0.19 percentage points. In the 1987-2000 and 2000-2010 sub-periods, the difference between the highest and the lowest TFP estimates is 0.28 percentage points for Canada and 0.35 percentage points for the US.

Table 3.8 shows that the TFP growth differential between 1987-2000 and 2000-2010 was robust to alternative assumptions and methodologies, especially for Canada, where it averaged at -0.66 percentage points across the eight scenarios – ranging from -0.71 percentage points (Bus6) to -0.62 percentage points (Bus2). For the US, the TFP growth differential averaged 0.41 percentage points, ranging from 0.21 percentage points (Bus4) to 0.62 percentage point (Bus5). Regardless of the methodology adopted, these estimates show that Canada's weak TFP performance (compared to that of the US) became even more pronounced in the post-2000 period (Table 3.9).

Table 3.8 TFP Growth Difference between 1987-2000 and 2000-2010 in the Canadian and the US Business Sector (Percentage Points)

	Canada	US
Bottom-up Approach		
Bus1: StatCan depreciation and equal nominal rate of return	-0.63	0.43
Bus2: StatCan depreciation and equal real rate of return	-0.62	0.36
Bus3: BEA depreciation and equal nominal rate of return	-0.66	0.28
Bus4: BEA depreciation and equal real rate of return	-0.65	0.21
Top-down Approach		
Bus5: StatCan depreciation and equal nominal rate of return	-0.69	0.62
Bus6: StatCan depreciation and equal real rate of return	-0.71	0.57
Bus7: BEA depreciation and equal nominal rate of return	-0.64	0.44
Bus8: BEA depreciation and equal real rate of return	-0.66	0.39

Table 3.9 TFP Growth Difference between the Canadian and the US Business Sector (Percentage Points)

	US-Canada		
	1987-2000	2000-2010	1987-2010
Bottom-up Approach			
Bus1: StatCan depreciation and equal nominal rate of return	0.16	1.22	0.61
Bus2: StatCan depreciation and equal real rate of return	0.21	1.19	0.64
Bus3: BEA depreciation and equal nominal rate of return	0.15	1.09	0.55
Bus4: BEA depreciation and equal real rate of return	0.19	1.05	0.56
Top-down Approach			
Bus5: StatCan depreciation and equal nominal rate of return	0.29	1.60	0.86
Bus6: StatCan depreciation and equal real rate of return	0.32	1.60	0.88
Bus7: BEA depreciation and equal nominal rate of return	0.38	1.46	0.84
Bus8: BEA depreciation and equal real rate of return	0.40	1.45	0.86

3.6 Conclusion

There is no question that different methodologies produce different TFP growth estimates due to inefficient input markets and heterogeneous industries. The real question is: how different are they? In this chpater, we studied the sensitivity of TFP growth rates to alternative methodologies by industry and by the business sector for both Canada and the US.

We started the investigation on an equal footing for both Canada and the US with fairly comparable raw data, including information on 18 types of workers and 27 different asset types at the industry level. We considered three alternative methodologies/assumptions in estimating output and inputs: Statistics Canada or BEA asset deprecation rates (for capital services), equal nominal or real rates of return of capital across all assets (for capital services), and the top-down or the bottom-up approach (for aggregation).

We found that TFP growth estimates under these alternative methodologies can vary, and yet the differences are relatively small. We showed the TFP growth estimates are in general robust to the choice of methodologies and assumptions. The robustness checks confirm that TFP growth in Canada has indeed slowed in the post-2000 period (especially after 2005) and that the US has outperformed Canada by a wide margin over this period.

Our capital and labour services indexes based on the bottom-up approach for the business sector are in general consistent with the CPP estimates at Statistics Canada. However, a comparison has to be made with caution since there are several major differences in the two estimations. First, the CPP uses much more disaggregated data on asset type, labour composition and industry classification. Second, value added in our analysis is measured at factor cost while it is measured at basic prices under the CPP. Third, our classification of workers is the same as that in the EUKLEMS program, but it differs from the CPP. In particular, we have three types of education levels while the CPP uses five. Fourth, our investment data are directly from the Investment and Capital Stock Division at Statistics Canada. For the CPP, they are benchmarked to the investment estimates in the final demand matrix of the input/output tables. Finally, following the EUKLEMS program, we exclude land and inventory in our capital input estimation, while they are included by the CPP.[32]

It is also important to note that for our analysis, the underlying data and their sources are the same for all scenarios discussed. TFP growth estimates could well be different when raw data are different. In addition, our scenarios, which are based on three different methodological assumptions, are not exhaustive. For future research, the robustness check performed here could be extended to include different levels of detail in terms of asset type, labour composition or industry classifications, although we do not expect that the new effort will produce substantially different TFP growth estimates.

[32] Note that the presence of land and inventory will reduce the rate of return to capital. It will also lead to higher TFP growth rates since these two assets tend to "move" slowly.

Appendix Tables

Table A3.1 Labour Productivity Growth by Industry in Canada and the US, 1987-2010 (Average Annual Growth Rate, Percent)

	Canada			US		
	1987-2010	2000-2010	1987-2010	1987-2010	2000-2010	1987-2010
Agriculture, forestry, fishing, and hunting	3.4	3.7	3.6	4.3	2.5	3.5
Mining	2.0	-2.8	-0.1	2.0	-2.6	0.0
Oil and gas extraction	4.5	-5.6	0.1	-0.5	-1.7	-1.0
Mining, except oil and gas, and support activities	0.6	-1.4	-0.2	6.1	-3.7	1.8
Utilities	0.0	0.0	0.0	2.8	-0.3	1.5
Construction	-0.4	0.0	-0.2	0.1	-1.8	-0.7
Manufacturing	3.2	0.9	2.2	3.7	5.5	4.5
Wood products	1.6	5.3	3.2	-1.9	5.1	1.2
Non-metallic mineral products	1.6	0.6	1.2	1.9	-0.1	1.0
Primary metals	4.7	2.4	3.7	2.5	0.9	1.8
Fabricated metal products	1.2	-0.6	0.4	1.0	0.8	0.9
Machinery	2.6	0.7	1.8	0.6	5.0	2.5
Computer and electronic products	9.5	-2.0	4.5	21.7	21.6	21.6
Electrical equipment, appliances, and components	3.6	-2.1	1.1	1.0	4.0	2.3
Motor vehicles, bodies and trailers, and others	4.9	0.9	3.2	-0.1	0.5	0.2
Furniture and related products, and miscellaneous	2.7	-0.5	1.3	3.0	5.6	4.2
Food, beverage, and tobacco products	1.5	0.4	1.0	0.8	0.8	0.8
Textile mills and textile product mills	1.1	1.2	1.2	3.4	6.5	4.7
Apparel and leather and allied products	2.0	0.4	1.3	3.5	10.1	6.4
Paper products, printing and related support activities	2.0	0.5	1.3	-0.1	2.2	0.9
Petroleum and coal products	3.3	-2.5	0.8	6.3	7.4	6.8
Chemical products	4.1	-1.0	1.9	1.2	2.5	1.7
Plastics and rubber products	2.8	0.7	1.9	3.2	2.5	2.9
Wholesale trade	2.6	3.1	2.9	4.7	2.7	3.8
Retail trade	3.0	2.5	2.8	3.9	2.3	3.2
Transportation and warehousing	1.0	1.0	1.0	1.8	1.9	1.8
Information	2.0	2.2	2.1	1.4	8.5	4.5
FIRE, Management of companies and enterprises	1.4	1.5	1.4	2.0	1.6	1.8
Professional, scientific, and technical services	0.2	0.5	0.3	0.7	2.1	1.3
Administrative and waste management	1.4	0.0	0.8	0.2	2.8	1.4
Education and Health care and social assistance	-2.1	-0.1	-1.2	-1.8	0.4	-0.9
Arts, entertainment, and recreation	-0.8	-0.9	-0.8	1.0	0.7	0.9
Accommodation and food services	0.7	0.5	0.6	1.0	0.6	0.8
Other services (except public admin)	-1.0	0.8	-0.3	0.3	-1.7	-0.6
Business sector						
Bottom-up approach	1.3	0.7	1.0	1.8	2.1	1.9
Top-down approach	1.3	0.6	1.0	2.0	2.4	2.1

Note: Labour productivity is defined as real value added per hour worked.

Table A3.2 TFP Growth by Industry in Canada and the US, 1987-2000 (Average Annual Growth Rate, Percent)

	Canada				US			
	Ind1	**Ind2**	**Ind3**	**Ind4**	**Ind1**	**Ind2**	**Ind3**	**Ind4**
Agriculture, forestry, fishing, and hunting	3.6	3.6	3.2	3.2	3.5	3.6	3.3	3.3
Mining	0.3	0.3	0.1	0.1	1.0	1.0	0.7	0.7
Oil and gas extraction	0.1	0.1	0.1	0.1	-3.0	-3.0	-3.4	-3.4
Mining, except oil and gas, and support activities	1.1	1.1	0.4	0.4	5.4	5.5	5.3	5.3
Utilities	0.3	0.4	-0.4	-0.3	1.7	1.7	1.0	1.0
Construction	-1.1	-1.1	-1.1	-1.1	-1.3	-1.3	-1.3	-1.2
Manufacturing	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2
Wood products	0.8	0.8	0.9	1.0	-2.3	-2.3	-2.3	-2.2
Non-metallic mineral products	0.5	0.6	0.6	0.7	1.2	1.2	1.4	1.4
Primary metals	3.6	3.6	3.6	3.6	2.1	2.2	2.1	2.1
Fabricated metal products	1.4	1.4	1.4	1.4	0.2	0.2	0.2	0.3
Machinery	1.6	1.6	1.7	1.7	-1.3	-1.2	-1.2	-1.1
Computer and electronic products	7.2	7.3	7.3	7.4	19.2	19.3	19.3	19.4
Electrical equipment, appliances, and components	1.7	1.8	1.8	1.8	-0.4	-0.4	-0.7	-0.6
Motor vehicles, bodies and trailers, and others	3.6	3.6	3.4	3.4	-1.6	-1.6	-1.6	-1.5
Furniture and related products, and miscellaneous	1.9	1.9	2.0	2.0	1.8	1.9	1.9	1.9
Food, beverage, and tobacco products	0.2	0.2	0.3	0.3	0.1	0.1	0.0	0.0
Textile mills and textile product mills	0.5	0.5	0.4	0.4	2.4	2.4	2.3	2.4
Apparel and leather and allied products	1.1	1.2	1.1	1.1	0.8	0.8	0.8	0.8
Paper products, printing and related support activities	0.7	0.8	0.6	0.7	-1.0	-1.0	-1.1	-1.1
Petroleum and coal products	2.2	2.3	2.1	2.1	5.0	5.1	4.5	4.6
Chemical products	2.6	2.7	2.5	2.5	-1.6	-1.5	-1.4	-1.3
Plastics and rubber products	2.1	2.1	2.1	2.2	1.9	1.9	2.0	2.0
Wholesale trade	1.0	1.0	1.3	1.3	3.3	3.4	3.2	3.3
Retail trade	1.9	1.9	2.0	2.0	2.6	2.7	2.7	2.8
Transportation and warehousing	-0.1	0.0	0.1	0.2	1.1	1.3	1.4	1.7
Information	-0.1	-0.1	0.1	0.1	-0.9	-0.5	-0.8	-0.6
FIRE, Management of companies and enterprises	-0.4	-0.3	-0.6	-0.5	-1.0	-0.9	-1.3	-1.1
Professional, scientific, and technical services	-2.5	-2.5	-2.4	-2.3	-1.9	-1.9	-1.6	-1.5
Administrative and waste management	0.9	1.0	1.3	1.4	-0.4	-0.3	-0.4	-0.4
Education and Health care and social assistance	-2.2	-2.1	-2.1	-2.0	-2.3	-2.2	-2.3	-2.2
Arts, entertainment, and recreation	-1.8	-1.7	-1.9	-1.8	-0.5	-0.5	0.0	0.1
Accommodation and food services	0.3	0.3	0.1	0.1	0.7	0.7	0.6	0.6
Other services (except public admin)	-2.2	-2.1	-1.8	-1.7	-0.3	-0.2	-0.1	-0.1
Correlations by Approach								
Ind1: StatCan depreciation, equal nominal rate of return	1.000	1.000	0.992	0.992	1.000	1.000	0.998	0.998
Ind2: StatCan depreciation, equal real rate of return		1.000	0.992	0.992		1.000	0.998	0.998
Ind3: BEA depreciation, equal nominal rate of return			1.000	1.000			1.000	1.000
Ind4: BEA depreciation, equal real rate of return				1.000				1.000

Table A3.3 TFP Growth by Industry in Canada and the US, 2000-2010 (Average Annual Growth Rate, Percent)

	Canada				US			
	Ind1	**Ind2**	**Ind3**	**Ind4**	**Ind1**	**Ind2**	**Ind3**	**Ind4**
Agriculture, forestry, fishing, and hunting	2.3	2.4	2.1	2.1	0.3	0.3	0.6	0.6
Mining	-5.3	-5.2	-5.1	-5.0	-2.8	-2.9	-2.4	-2.6
Oil and gas extraction	-5.8	-5.8	-5.9	-5.8	-2.2	-2.5	-1.8	-2.2
Mining, except oil and gas, and support activities	-3.7	-3.5	-2.7	-2.5	-4.5	-4.4	-4.2	-4.1
Utilities	-0.5	-0.4	-0.2	-0.1	-2.9	-2.6	-2.4	-2.3
Construction	-0.3	-0.3	-0.3	-0.3	-3.4	-3.4	-3.5	-3.5
Manufacturing	-0.1	0.0	-0.4	-0.4	3.3	3.3	3.2	3.2
Wood products	3.7	3.7	3.1	3.1	4.2	4.2	4.0	4.0
Non-metallic mineral products	-0.4	-0.3	-0.3	-0.2	-1.5	-1.5	-1.6	-1.6
Primary metals	2.1	2.2	1.5	1.5	-1.2	-1.2	-0.9	-0.9
Fabricated metal products	-1.2	-1.2	-1.4	-1.3	-0.2	-0.2	-0.4	-0.4
Machinery	0.2	0.2	-0.1	-0.1	4.2	4.2	3.8	3.8
Computer and electronic products	-2.9	-2.9	-3.3	-3.3	20.1	20.2	19.8	19.8
Electrical equipment, appliances, and components	-2.7	-2.7	-2.9	-2.9	2.5	2.6	2.1	2.1
Motor vehicles, bodies and trailers, and others	-0.4	-0.3	-0.8	-0.7	1.4	1.4	1.2	1.2
Furniture and related products, and miscellaneous	-1.9	-1.8	-2.1	-2.1	5.1	5.1	4.9	4.9
Food, beverage, and tobacco products	0.4	0.5	0.2	0.3	-0.2	-0.2	-0.4	-0.3
Textile mills and textile product mills	0.3	0.3	-0.4	-0.4	4.5	4.5	3.7	3.7
Apparel and leather and allied products	-0.3	-0.3	-0.8	-0.8	7.2	7.2	6.5	6.5
Paper products, printing and related support activities	1.1	1.1	0.5	0.5	2.9	3.0	2.6	2.6
Petroleum and coal products	-6.2	-5.4	-5.9	-4.9	1.1	1.2	3.2	3.3
Chemical products	0.3	0.3	-0.4	-0.4	1.3	1.4	0.8	0.9
Plastics and rubber products	-0.4	-0.4	-0.7	-0.7	1.2	1.2	0.7	0.7
Wholesale trade	1.5	1.5	1.5	1.6	1.4	1.4	1.3	1.3
Retail trade	1.3	1.4	1.4	1.5	1.1	1.1	0.9	0.9
Transportation and warehousing	0.0	0.1	0.1	0.2	2.1	2.0	2.0	1.9
Information	1.3	1.4	0.9	1.0	5.4	5.5	4.9	5.0
FIRE, Management of companies and enterprises	0.9	1.0	0.6	0.8	0.8	0.8	0.3	0.4
Professional, scientific, and technical services	-0.1	-0.1	-0.2	-0.2	0.0	0.0	-0.1	0.0
Administrative and waste management	-1.3	-1.2	-0.5	-0.5	2.1	2.1	2.0	2.1
Education and Health care and social assistance	-0.6	-0.6	-0.5	-0.4	-1.0	-1.0	-1.0	-0.9
Arts, entertainment, and recreation	-1.6	-1.5	-1.6	-1.6	-0.4	-0.3	-0.5	-0.4
Accommodation and food services	-0.3	-0.3	-0.2	-0.2	0.0	0.0	-0.1	0.0
Other services (except public admin)	0.3	0.3	0.5	0.6	-2.7	-2.7	-2.8	-2.8
Correlations by Approach								
Ind1: StatCan depreciation, equal nominal rate of return	1.000	0.999	0.987	0.981	1.000	1.000	0.994	0.994
Ind2: StatCan depreciation, equal real rate of return		1.000	0.986	0.984		1.000	0.994	0.994
Ind3: BEA depreciation, equal nominal rate of return			1.000	0.997			1.000	1.000
Ind4: BEA depreciation, equal real rate of return				1.000				1.000

Table A3.4 Source of Labour Productivity Growth in the Canadian Business Sector

	Labour Productivity Growth (average annual growth rate, percent)	Contributions (percentage points)				
		Labour Quality Growth	**Structure Capital Intensity Growth**	**ICT Capital Intensity Growth**	**Non-ICT Capital Intensity Growth**	**TFP Growth**
1987-2010						
Bottom-up Approach						
Bus1	1.02	0.05	0.14	0.48	0.19	0.17
Bus2	1.02	0.05	0.14	0.45	0.17	0.21
Bus3	1.02	0.05	0.21	0.44	0.18	0.15
Bus4	1.02	0.05	0.21	0.40	0.16	0.21
Top-down Approach						
Bus5	0.98	0.25	0.12	0.47	0.17	-0.03
Bus6	0.98	0.25	0.13	0.43	0.15	0.01
Bus7	0.98	0.25	0.18	0.43	0.15	-0.03
Bus8	0.98	0.25	0.19	0.39	0.13	0.02
1987-2000						
Bottom-up Approach						
Bus1	1.25	0.05	0.02	0.57	0.17	0.44
Bus2	1.25	0.05	0.03	0.53	0.16	0.48
Bus3	1.25	0.05	0.10	0.51	0.16	0.43
Bus4	1.25	0.05	0.10	0.46	0.15	0.49
Top-down Approach						
Bus5	1.25	0.32	-0.01	0.54	0.13	0.27
Bus6	1.25	0.32	0.00	0.50	0.11	0.32
Bus7	1.25	0.32	0.08	0.49	0.12	0.24
Bus8	1.25	0.32	0.08	0.44	0.10	0.31
2000-2010						
Bottom-up Approach						
Bus1	0.72	0.04	0.30	0.37	0.20	-0.19
Bus2	0.72	0.04	0.30	0.34	0.18	-0.14
Bus3	0.72	0.04	0.36	0.35	0.20	-0.23
Bus4	0.72	0.04	0.36	0.31	0.17	-0.16
Top-down Approach						
Bus5	0.62	0.17	0.29	0.37	0.21	-0.42
Bus6	0.62	0.17	0.30	0.34	0.20	-0.39
Bus7	0.62	0.17	0.32	0.34	0.19	-0.40
Bus8	0.62	0.17	0.32	0.31	0.17	-0.35

Note: Labour productivity is defined as real value added per hour worked.

Table A3.5 Source of Labour Productivity Growth in the US Business Sector

	Labour Productivity Growth (average annual growth rate, percent)	**Contributions** (percentage points)				
		Labour Quality Growth	**Structure Capital Intensity Growth**	**ICT Capital Intensity Growth**	**Non-ICT Capital Intensity Growth**	**TFP Growth**
			1987-2010			
Bottom-up Approach						
Bus1	1.95	0.01	0.04	0.82	0.29	0.78
Bus2	1.95	0.01	0.04	0.76	0.28	0.85
Bus3	1.95	0.01	0.20	0.75	0.28	0.70
Bus4	1.95	0.01	0.21	0.68	0.28	0.77
Top-down Approach						
Bus5	2.14	0.23	0.07	0.77	0.23	0.83
Bus6	2.14	0.23	0.07	0.72	0.22	0.89
Bus7	2.14	0.23	0.17	0.71	0.21	0.81
Bus8	2.14	0.23	0.18	0.64	0.20	0.88
			1987-2000			
Bottom-up Approach						
Bus1	1.81	-0.02	-0.05	1.04	0.26	0.60
Bus2	1.81	-0.02	-0.06	0.96	0.24	0.69
Bus3	1.81	-0.02	0.08	0.93	0.24	0.58
Bus4	1.81	-0.02	0.08	0.84	0.24	0.68
Top-down Approach						
Bus5	1.95	0.28	-0.06	0.99	0.18	0.56
Bus6	1.95	0.28	-0.06	0.92	0.18	0.64
Bus7	1.95	0.28	0.03	0.89	0.14	0.62
Bus8	1.95	0.28	0.03	0.80	0.14	0.71
			2000-2010			
Bottom-up Approach						
Bus1	2.11	0.05	0.17	0.53	0.34	1.03
Bus2	2.11	0.05	0.17	0.50	0.33	1.05
Bus3	2.11	0.05	0.35	0.51	0.34	0.86
Bus4	2.11	0.05	0.37	0.47	0.33	0.89
Top-down Approach						
Bus5	2.39	0.18	0.23	0.49	0.30	1.18
Bus6	2.39	0.18	0.24	0.47	0.28	1.21
Bus7	2.39	0.18	0.36	0.48	0.30	1.06
Bus8	2.39	0.18	0.38	0.44	0.28	1.10

Note: Labour productivity is defined as real value added per hour worked.

Chapter 4 Canada-US Manufacturing Total Factor Productivity: Short- and Long-Run Relationships

4.1 Introduction

Canada and the US are highly integrated economies. In addition to extensive bilateral trade and investment, the countries share a common language. They have similar market structures and regulation, and labour is fairly mobile between the two countries. All these features suggest that productivity at the sector and/or industry level should be similar across the countries. However, significant and persistent productivity gaps exist between Canadian and US industries (e.g., Cerisla and Chan-Lau, 2000, Bernstein *et al.*, 2002, Baldwin and Gu, 2007, and Li, Shute and Tang, 2013). Researcher have sought to explain the widening productivity gap since 2000 in terms of measurement issues (Baldwin and Green, 2008), high capital intensity (Tang, Rao and Li, 2010), and low capacity utilization in capital (Gu and Wang, 2012).

The motivation of this chapter is twofold. First, this chapter seeks to find whether there is a long-run relationship in total factor productivity (TFP) between Canada and the US in manufacturing on an industry-by-industry basis. Second, the chapter attempts to identify whether US industry innovations have an immediate and/or cumulative impact, if any, on Canadian counterparts. The chapter does not attempt to address the underlying reasons for the existing gap. Instead, it attempts to document the extent to which Canadian manufacturing industries depend upon their US counterparts.

The chapter investigates cross-border interdependence by industry, using TFP growth estimates established from the previous chapter on Canadian and US manufacturing from 1987-2010. It first examines whether TFP converges by industry in the two countries. The empirical approach follows most closely to Bernard and Jones (1996a); it is commonly adopted in the literature to capture productivity catch-up effects yet implicitly assumes a common growth pattern in the long-run productivity. The chapter subsequently relaxes this assumption, while still allowing Canada's TFP growth to depend upon its US counterpart. With no evident convergence, the chapter proceeds with simple bivariate VAR models of US and Canadian TFPs. The advantage of this approach is that it not only allows one to examine both the short- and long-run impacts of US productivity innovations on Canadian counterparts but also lays down a benchmark for the dynamic panel analysis in the next chapter.

Two main findings emerge from the study. First, little evidence is found for long-run convergence of industry TFPs for 1987-2010. Second, the industry-level VAR analysis finds that technology diffusion is not uniform across industries. A small handful of Canadian industries, as well as Canadian manufacturing as a whole, are found to respond positively to productivity innovations in their US counterparts. The remaining industries exhibit little significant response except one where a negative response is found. When the effect of innovations from US manufacturing as a whole is considered, there appears to be a greater number of industries with positive responses. This, in turn, suggests a potential role for cross-border demand shocks as opposed to pure transfers of industry-specific technology. Furthermore, nearly half of the variation in Canadian productivity growth at the sector level (that is manufacturing as a whole) can be explained by productivity innovations from its US counterpart yet on an industry-by-industry basis the evidence is mixed for a role for US innovations in contributing to Canadian TFP growth.

The rest of the chapter is structured as follows. Section 4.2 lays out the empirical framework. Section 4.3 discusses the data source and summary statistics. Section 4.4 presents the empirical analysis, followed by conclusions in Section 4.5.

4.2 Empirical Framework

4.2.1 Long-Run Convergence

Let X_{it} and X_{it}^* denote domestic and foreign total factor productivity (TFP), respectively, for industry i at time t. Assume that a general steady state relationship links the two as follows:

$$X_{it} = e^{\alpha}(X_{it}^{*})^{\beta}$$

The linear long-run relationship for TFPs can then be expressed in logarithms:

$$x_{it} = \alpha + \beta x_{it}^{*},$$

where $x_{it} \equiv \log X_{it}$ and $x_{it}^{*} \equiv \log X_{it}^{*}$.

Three possible scenarios arise from this expression. First, both countries, domestic and foreign, have access to common technology. In this case, one would expect technology to diffuse perfectly; that is, $x_{it} = x_{it}^{*}$ in the long run with $\alpha = 0$ and $\beta = 1$. Second, it is possible that domestic and foreign technology grow at some common rate ($\beta = 1$), with a stable discrepancy between them at all times ($\alpha \neq 0$). This may arise due to different business environments, such as institutional conditions and patent protection. Finally, technology by industry is asymmetric across borders and yet domestic technology depends upon foreign technology through the process of diffusion. In this case, one would expect domestic technology to be proportional to the foreign counterpart ($\alpha \neq 0$) and not to share a common long-run growth rate ($\beta \neq 1$). This last scenario may arise due to 1) different investments in research and development and education system; and 2) stable compositional effect with technology specific to sub-industries. Say, the Canadian chemical industry, for example, centres on one part of chemical products while the US on another, resulting in a different technological level and change that are specific to each sub-industry in steady state.

Empirically, if x_{it} and x_{it}^{*} follow random walks with drifts, which will be the working assumption here, one would expect x_{it} and x_{it}^{*} to be cointegrated with a $(1, -1)$ cointegrating vector in the first two scenarios. In other words, the productivity gap, $z_t \equiv x_{it} - x_{it}^{*}$, is expected to be stationary. In contrast, one would expect x_{it} and x_{it}^{*} to be cointegrated in the last scenario with non-unit long-run elasticity, β. In any event, the existence of cointegration gives rise to an error correction model for productivity growth rates under the assumption that foreign technology (in logarithm) follows a random walk with drift.

The specification of technology diffusion in the first two scenarios is closely related to the earlier work by Bernard and Jones (1996a), which proposes and tests whether the relative productivity levels, or productivity gaps, are stationary around a nonzero mean. Rejection of the null hypothesis of a unit root in the productivity gaps provides evidence for convergence in technology. This stationary productivity gap, in turn, can be used in explaining a follower country's technological advancement through the catch-up effect to its leader country. Cameron, Proudman and Redding (2005), for example, examines multi-factor productivity growth in UK manufacturing industries as dependent upon catch-up to US counterpart industries. They specify an error correction model for UK manufacturing productivity growth with unit elasticity, which implicitly assumes the stationarity in productivity gap from the US.

The third scenario, however, is where the paper departs from these earlier studies. In the current dataset the productivity gaps between Canadian and US industries are not stationary. It is therefore natural to relax the assumption of unit elasticity and to test for a more general cointegration and if evident, use a more general error correction framework. Alternatively, if no evidence of cointegration exists, then the analysis is left with modelling the industry interdependence using productivity growth rates alone and no role for the catch-up effect due to productivity gap.

4.2.2 Industry-Specific Bivariate VAR Models

As to be demonstrated below, there is no evidence for long-run convergence on an industry-by-industry basis, or in terms of the manufacturing sector as a while. This general result is similar to earlier work by Bernard and Jones (1996a). These authors consider fourteen OECD countries and broad sectoral aggregates during 1970-1987, including the manufacturing sector. While many sectors show evidence of convergence in productivity (e.g., service, electricity/gas/water), there is little evidence of convergence in manufacturing. They explain this result by arguing manufacturing, comprising tradable goods, is likely to be relatively specialized so that there is less scope for productivity diffusion. Whether or not this explanation is correct, the current data set adds new evidence to Bernard and Jones's existing evidence but at a more detailed level considering as it does specific manufacturing industries.

With no stationary relationships between US and Canadian productivity levels, I consider industry-specific VAR models of US and Canadian TFP growth rates to model the cross-border dependence. In order to identify the effect of US productivity on the Canadian counterparts, I assume a recursive ordering of US and Canadian TFPs. This amounts to treating contemporaneous US productivity as exogenous for Canadian productivity while excluding contemporaneous Canadian productivity from the regression equation for US productivity. That is, for each industry *i* at time *t* productivity growth can be expressed as:

$$\begin{aligned} \mathbf{\Delta}x_{it}^{*} &= c_1 + b_{11}^{1}\mathbf{\Delta}x_{it-1}^{*} + b_{12}^{1}\mathbf{\Delta}x_{it-1} + u_{1t} \\ \mathbf{\Delta}x_{it} &= c_2 + b_{21}^{0}\mathbf{\Delta}x_{it}^{*} + b_{21}^{1}\mathbf{\Delta}x_{it-1}^{*} + b_{22}^{1}\mathbf{\Delta}x_{it-1} + u_{2t} \end{aligned} \tag{4.2}$$

for $t = 2 \ldots T$. u_{1t} and u_{2t} are i.i.d. with structural innovations $Eu_{1t}u_{2t} = 0$. For ease of notation, I have not indicated the dependence of the coefficients or disturbances on industry *i*. For the same reason I have presented the model with a lag order of one.[33]

Within this framework, the analysis considers the effects of US productivity shocks on their Canadian counterparts. In particular, it focuses on two types of effects. First, the dynamics of the effects of US productivity shocks on Canadian productivity levels, both in the short run and the long run. Even though there is no long-run relationship in productivity levels it is still possible for US shocks to permanently affect the level of Canadian productivity. Second, the overall contribution of US-based innovations to variation in Canadian productivity growth through the forecast error variance decompositions. In this way, these models provide a simple means of describing the short-run as well as the long-run dynamics between US and Canadian TFPs by industry.[34]

4.3 Data

4.3.1 Data Background and Challenges

Statistics Canada did not initiate its multi-factor productivity (MFP) program until the 1970s, when the well documented labour productivity slow-down motivated efforts to

[33] The SVAR model above is equivalent to the more standard presentation of a reduced form VAR model with a Choleski decomposition on the disturbances. I present it in this format because it is closely related to the dynamic panel model in the following chapter.

[34] Even though the two series for each industry are not cointegrated, they still have unit roots so that shocks can have permanent effects on productivity levels. The cumulative impulse response function will provide information in this regard. One criticism of the above model is that it is possible for Canadian TFP shocks to have permanent effects on US productivity. An alternative identification strategy would be to restrict short and long-run effects of Canadian TFP shocks on US productivity to zero, i.e., b_{12}^{1} =0. Doing so has little effect on any of the conclusions.

separate embodied technological changes for the capital deepening process in labour productivity measures. In the beginning only fixed reproducible assets (machinery and equipment, or ME, and structure) were included for capital data construction (Baldwin and Gu, 2013). Over the years, MFP measures provided by Statistics Canada underwent quality adjustments for various inputs as well as development of alternative output measures (gross output versus value added).

In 2002, MFP measures were "re-engineered" (Baldwin and Gu, 2013 p.13). The growth rates of inputs, labour and capital, were re-estimated accounting for the heterogeneity of each input. Moreover, the asset detail of machinery and equipment ME and structure was expanded to 28 types. Along with the introduction of productive land and inventories, the new asset categorization of total 30 types made direct cross-country comparison with Bureau of Labour Statistics (BLS) possible. A new set of depreciation rate estimates were also introduced in the same year that made use of the rate of decline in asset prices after purchase (Gellatly, Tanguay and Yan, 2002). The 2002 revision resulted in two major differences in the MFP estimates. First, it reallocates economic growth towards input growth, resulting in lowers MFP growth estimates. Second, the revision resulted in a more methodologically sound comparisons of MFP growth in Canada and the US (Baldwin and Gu, 2013).

Despite the improvement in measurements over the recent decade, the direct cross-border comparability of MFP in manufacturing remains problematic (e.g., Baldwin and Green, 2008). For value added estimates Statistics Canada reports by domestic gross product (GDP) while the US Bureau of Economic Analysis (BEA) reports by sectoral output. At the sector level these two concepts are equivalent whereas at the industry level sectoral output excludes inter-industry deliveries within a sector. Moreover, value added is evaluated at different prices by Statistics Canada and the BEA, namely basic and market price, respectively.

For labour input estimates, Statistics Canada prepares labour input as hours worked adjusted for labour composition whereas the BEA does not. The quality or outcome of one-hour work by a university graduate is likely to differ from that by a grade-school graduate and hence their contributions to labour input should be treated differently.

The comparability issues become more complicated for capital inputs. Two concepts are relevant: capital stock versus capital service. Capital stock estimates are derived from fixed reproducible assets using the associated asset depreciation rates (see Chapter 3 for more discussion). Capital service, on the other hand, measures the service derived from capital stock and is a quality-adjusted measure of capital inputs (analogous to labour inputs). The comparability issue arises as Statistics Canada and the BEA adopt different asset depreciation rates in the perpetual inventory method (PIM) procedure (e.g., Tang, Rao and Li, 2010; Li, Shute and Tang, 2013). Moreover, Statistics Canada prepares capital input as capital service while the BEA considers capital stock.

In addition, the data coverage by these two agencies differs in time. Different industrial aggregation further hinders direct comparison. For instance, Statistics Canada reports food [311] and beverage and tobacco [312] separately while the BEA report these two industries as a whole.

Given the data challenges listed above, Chapter 3 goes to some lengths to develop consistent datasets for all variables required to construct comparable TFP growth estimates. The source of the dataset for both Canada and the US is briefly summarized below.[35]

4.3.2 Data Source

This study measures total factor productivity (TFP) as industrial real value added relative to hours worked by all employees and capital stock, adjusted for their compositional change over time. That is, TFP for industry *i* at time *t* is expressed as:

$$\Delta x_{it} = \Delta \ln Y_{it} - (\bar{v}_{it}^{L} \Delta \ln L_{it} + \bar{v}_{it}^{K} \Delta \ln K_{it}),$$

[35] See Chapter 3 for detailed discussion and data development.

where Y_{it} is real value added; L_t and K_t are labour and capital inputs respectively; $\bar{v}_{it}^{L}$ and $\bar{v}_{it}^{K}$ are the two-period average labour and capital income shares of value added, respectively. The TFP equation implies that the growth in TFP in industry *i* is the difference in growth between the real value added in that industry and a composite of labour and capital weighted by their cost ratios to value added. To obtain level TFP measures, the study benchmarks TFP growth rates using the first-year TFP level as 100.

The current dataset consists of sixteen manufacturing industries by North American Industry Classification System (NAICS) three-digit classification and manufacturing as a whole for the period 1987-2010. They are aggregated from six- and four-digit NAICS industries for Canada and the US, respectively, to ensure direct comparison in terms of amalgamations of certain industries. All data are annual.

Data on industry value added for Canada are a special tabulation from Statistics Canada that is consistent with CANSIM Table 379-0023 for nominal value added and is consistent with CANSIM Table 383-0021 for real value added. The US value added data by industry are from the BEA. To ensure comparability, the original data on value added are adjusted to value added at factor costs, using information on net indirect taxes for production from input-output tables from Statistics Canada for Canada and on both products and production from the BEA for the US.

Labour inputs are a product of labour quality and labour hours. Labour quality indexes are derived from labour matrices; they are from Statistics Canada for Canada and from EUKLEMS database for the US for 1987-2005, the latter extended to 2010 using the labour matrix from US Bureau of Labor Statistics (BLS). For hours worked, Canadian data are special tabulations from Statistics Canada that are consistent with CANSIM Table 383-0009 while the US data are from the BLS that are consistent with its prototype BEA/BLS Industry-level Production Account (Fleck *et al.*, 2012).

Capital inputs are constructed from investment and capital compensation by type of assets and by industry. Canadian data on investment in current and chained dollars by 175 asset types are based on investment surveys, which are conducted by the Investment and Capital Stock Division (ICSD) at Statistics Canada. The BEA provides US investment data by 74 assets in current and chained 2005 US dollars.[36] Capital compensation data source is identical to those for labour compensation.

4.3.3 Descriptive Summary

The sixteen three-digit NAICS industries (or amalgamations of certain industries) are identified in Table 4.1. For each industry and for both Canada and the US, I report the relative importance (as industrial shares of overall manufacturing), the average growth rate of value added, labour service, capital service, and the average total factor productivity (TFP) for the period 1987-2010.

All industries in Canada experience an expansion in value added except for four: (1) textiles; (2) apparel and leather; (3) paper and printing related activities; and (4) electrical equipment and appliances. In contrast, half of US manufacturing industries experience a contraction in value added, with the largest contraction in growth observed in textiles, apparel and leather. The production contractions in both countries' textiles and apparel and leather are not surprising as more labour intensive industries have seen a large scale of outsourcing over the past decades (e.g., Sachs *et al*., 1994, and Feenstra, 1998).

In terms of relative importance, the four largest industries in Canada are (1) transportation; (2) food, beverage and tobacco products; (3) paper, printing and related support activities; and (4) chemical products. Together these account for nearly 50 percent of Canadian manufacturing. For the US, the largest four industries are (1) transportation; (2) chemical product; (3) computer and electronics; and (4) food, beverage and tobacco products. The concentration pattern has remained fairly similar cross borders, with a slight shift towards computer and electronics in the US since 2008.[37]

[36] http://www.bea.gov/national/FA2004/Details/Index.html

[37] Machinery in the former top-4 list is replaced by computer and electronics (See Table 2.1 in Chapter 2).

Table 4.1 Data Statistics – Mean Growth Rates (Percent) over the Sampled Period

		Real Value Added		Relative Importance (industry share)		Labour Service		Capital Service		Total Factor Productivity	
		CAN	US	CAN	US	CAN	US	CAN	US	CAN	US
311, 312	Food, beverage, and tobacco products	0.8	0.7	14.6	10.5	0.1	0.4	1.1	1.4	0.3	-0.2
313, 314	Textile mills and textile product mills	-3.4	-1.9	1.5	2.0	-4.1	-6.1	-2.1	-1.4	0.4	2.9
315, 316	Apparel and leather and allied products	-4.5	-3.4	2.4	1.9	-5.6	-8.8	-1.6	-0.4	0.5	3.3
321	Wood products	1.3	-1.2	5.8	2.1	-1.6	-1.9	1.1	0.0	2.1	0.5
322, 323	Paper, printing and related support activities	-0.5	-1.1	10.4	7.2	-1.5	-2.4	-0.9	0.4	0.9	0.5
324	Petroleum and coal products	1.7	5.3	2.0	4.5	1.8	-1.1	4.2	2.1	-1.4	3.9
325	Chemical products	1.3	0.8	8.7	11.8	-0.1	-0.3	-0.5	2.6	1.6	-0.4
326	Plastics and rubber products	2.5	2.0	4.8	4.4	1.2	-0.4	2.5	2.2	1.0	1.4
327	Non-metallic mineral products	0.4	-0.3	3.0	2.8	-0.6	-0.9	1.4	0.6	0.1	0.1
331	Primary metals	1.6	-0.8	6.8	3.5	-1.8	-2.2	-0.7	-0.3	3.0	0.8
332	Fabricated metal products	1.3	0.1	6.9	8.1	1.2	-0.4	1.1	1.3	0.3	0.0
333	Machinery	2.1	1.1	6.6	7.8	0.8	-0.8	2.2	2.3	1.0	1.0
334	Computer and electronic products	3.4	19.1	4.7	11.4	-0.2	-1.9	1.3	5.0	2.8	19.5
335	Electrical equipment, appliances, and components	-0.9	-0.5	2.5	3.4	-1.4	-1.9	0.9	0.6	-0.2	0.5
336	Transportation equipment	2.0	-1.9	14.7	12.6	-0.8	-2.6	2.0	2.7	1.9	-0.4
337, 339	Furniture and miscellaneous	1.4	2.8	4.7	6.2	0.3	-1.9	3.3	2.1	0.2	3.2
31-33	Manufacturing	1.3	2.7	100.0	100.0	-0.5	-1.2	1.3	2.2	1.2	2.6

Note: Sample is 1987-2010. Relative importance measures the average value added by Canadian industry relative to total value added in Canadian manufacturing.

The growth in labour service in both countries sees an overall decline in the manufacturing sector. At the industry level, two thirds of the Canadian manufacturing industries experience such decline. The largest decline is seen in apparel and leather followed by textiles, similar to the US. In contrast, all US industries (except one, food, beverage, and tobacco) undergo a reduction in labour service and to a greater magnitude than their Canadian counterparts, suggesting a relatively slow labour adjustment in Canadian industries in comparison to that in their US counterparts.

Meanwhile both countries see an expansion in capital service growth in most manufacturing industries. A majority of Canadian industries experiences such expansion. The largest growth is observed in petroleum and coal, which is twofold faster in growth than its US counterpart. In comparison, a greater number of US industries sees capital expansion. The largest growth is found in computer and electronics. Moreover, capital expansion in US non-metallic mineral and computer and electronic industries is faster by a large margin than in their Canadian counterparts.

One general feature evident from Table 4.1 is that in terms of industry overall growth and patterns of industry input usage, Canadian and US manufacturing industries have quite different experiences over this period. This suggests that the similarities and/or the linkages across Canadian and US industries are weak, perhaps explaining the lack of convergence in productivity levels.

Compared to labour productivity growth (Table 2.1 in Chapter 2), TFP growth at both industry and sector levels are lower on average, suggesting that capital deepening underlies labour productivity.[38] Nevertheless, Canada's relative performance to the US is better in terms of TFP than in terms of labour productivity. Eight industries have a higher growth in TFP, compared to their US counterparts, as opposed to seven industries in the labour productivity investigation. Moreover, these eight industries amount to 70.9 percent of Canada's total value added in manufacturing in the current dataset. In

[38] It is worth bearing in mind that these estimates (labour productivity and industrial shares) in Chapter 2 are averaged over year 1987-2007. Moreover, the data set in Chapter 2 does not include the petroleum and coal industries.

comparison, the seven industries amounts to 57.9 percent of total manufacturing value added in the labour productivity study.

One outlier worth noting is computer and electronics, the third largest industry in the US, which sees a remarkably high annual growth in both value added and capital service, along with a decline in labour service growth. As a result, TFP growth averages an annual rate of nearly 20 percent - almost sevenfold larger than that in its Canadian counterpart.

A visual summary of these industries is provided in Figures 4.1-4.2 and 4.3-4.4, which plots TFP annual growth rates and indexes (1987=100) for each industry. Overall, there does appear to be some evidence of correlation in growth rates for some industries, suggesting that some cross-border interdependence between the industries exists. It is evident in Figures 4.2-4.3 that Canadian manufacturing at sectoral level has lagged behind in growth since 2000, despite the relatively steady growth in the four largest industries in Canada. Some part of this discrepancy is most likely attributable to substantial growth found in US computer and electronics.

4.4 Empirical Analysis

4.4.1 Time Series Analysis

As many of the productivity series appear non-stationary, I first examine whether the total factor productivity (TFP) measures have a unit root using the Elliot, Rothenberg, and Stock (1996) modified Dickey-Fuller (DF) statistics. A maximum lag order of two is used due to limited data length. The lag selection is based on Ng and Perron's (2000) modified Akaike Information Criteria (AIC).

Figure 4.1 TFP Growth in Manufacturing (Canada: Solid; US: Dashed; Relative Importance in Parentheses)

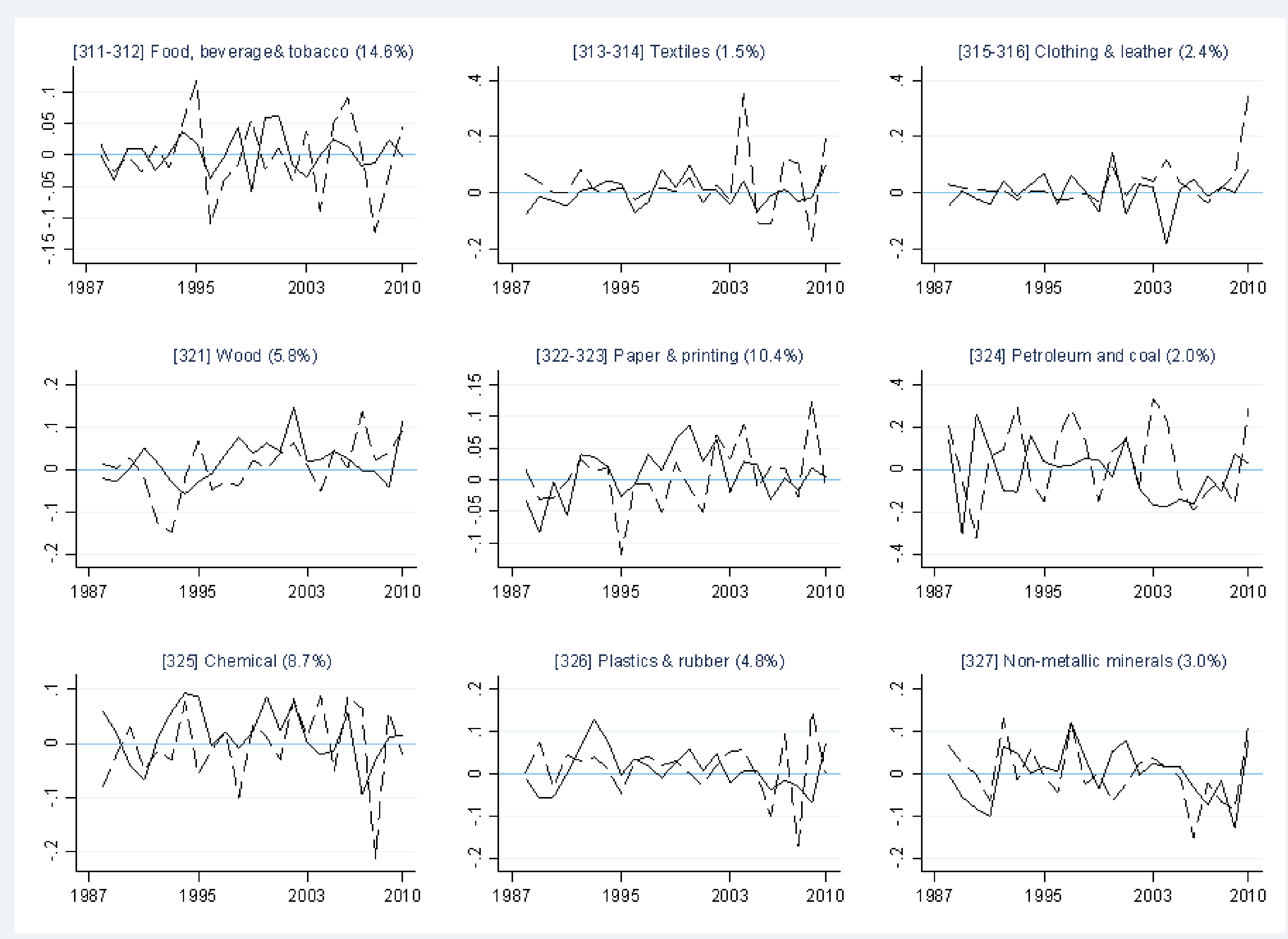


Figure 4.2 TFP Growth in Manufacturing (Canada: Solid; US: Dashed; Relative Importance in Parentheses)

Figure 4.3 TFP in Manufacturing, 1987=100 (Canada: Solid; US: Dashed; Relative Importance in Parentheses)

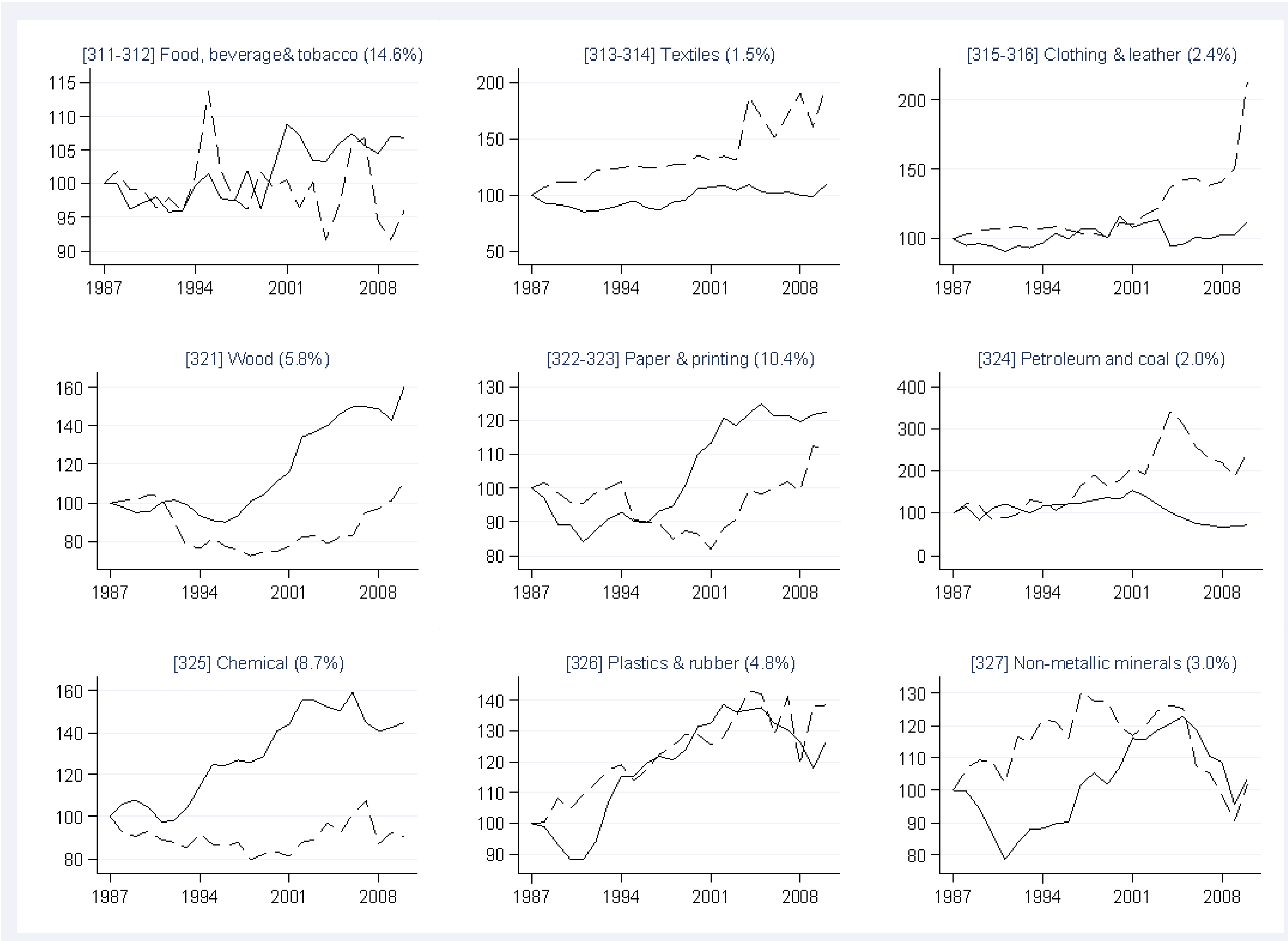
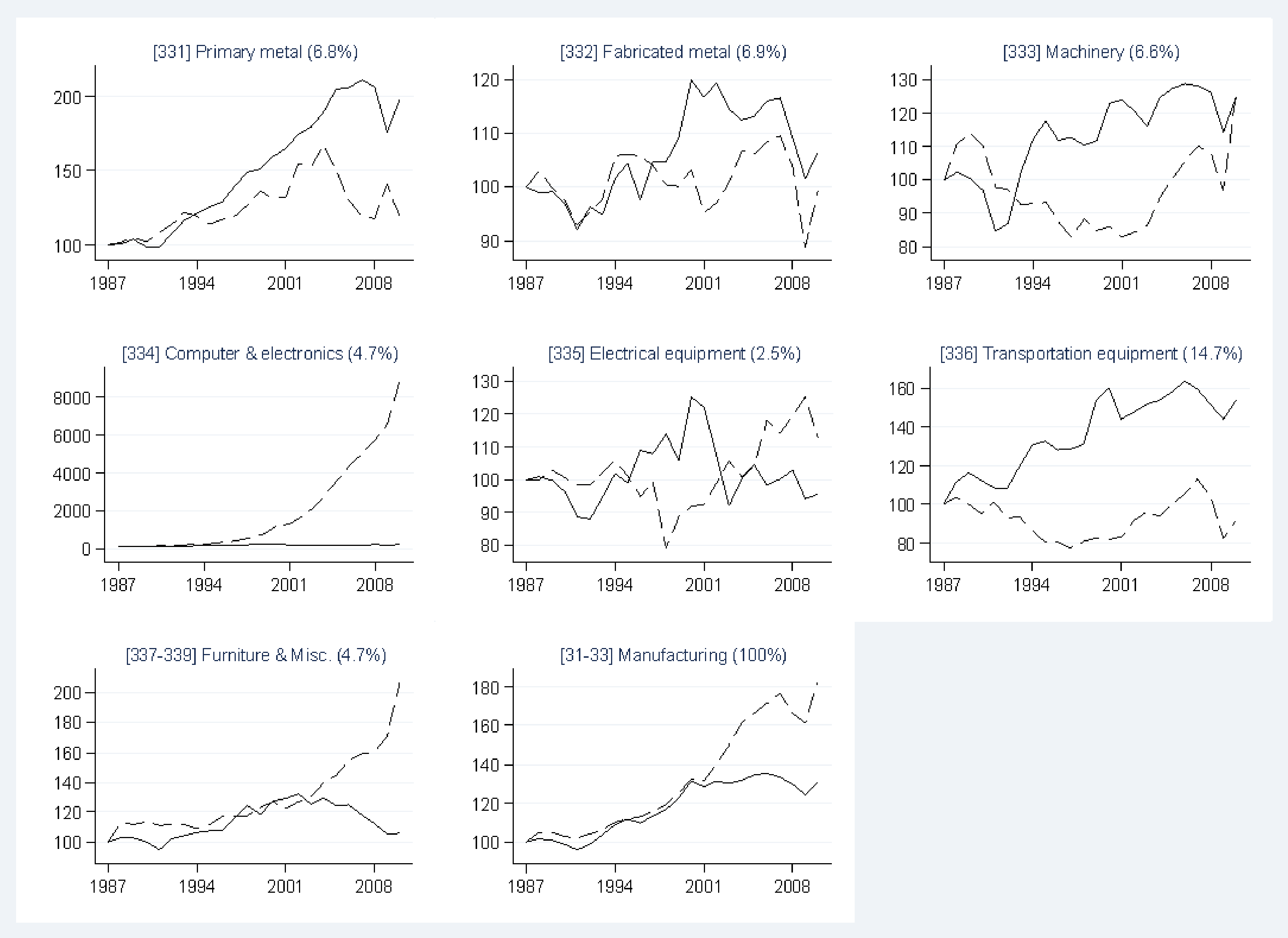


Figure 4.4 TFP in Manufacturing, 1987=100 (Canada: Solid; US: Dashed; Relative Importance in Parentheses)



Unit root tests for log level TFP series are presented in Table 4.2. For each industry in each country, the null hypothesis is that TFP has a unit root with a non-zero drift. For some industries, the TFP series exhibit a trend while for others no trend is evident (see Figures 4.3-4.4). Consequently, Table 4.2 reports unit root tests using test regressions with and without a linear trend. For most industries, as well as manufacturing sector as a whole, one cannot reject the null of a unit root. This holds true for both Canada and the US with a few exceptions. For Canada, TFP levels in machinery appear to be trend stationary; one cannot reject the null of a unit root against level stationarity yet rejects the null when a linear time trend is included in the test regression. For the US, TFP levels appear to be stationary, with or without a trend included in the test regression, in two industries: food, beverage and tobacco, and fabricated metal.

Now let us turn to TFP growth rates (log first difference). For most industries in both countries, the growth rates series do not exhibit any obvious trend (Figures 4.1-4.2). Consequently, the null hypothesis is that TFP growth rates have a unit root with a non-zero drift. Table 4.3 reports the results of these unit root tests. For most industries in Canada, as well as manufacturing sector, one can reject the null of non-stationarity at conventional significance levels. Four exceptions include: (1) apparel and leather; (2) paper and printing; (3) petroleum and coal; and (4) furniture and miscellaneous.

As far as US growth rates of TFP are concerned, one rejects the null of a unit root in half of manufacturing industries, as well as in the sector. For the rest of the industries non-stationarity issues persist. Inspection of growth rates in these industries (see Figure 4.2) shows a slight trend, indicating that these series might be best modelled with a trend. Under the alternative hypothesis that TFP growth rates are trend stationary, four industries remain wherein one cannot reject the null of a unit root (See Appendix Table A4.1). They include: (1) apparel and leather; (2) chemical products; (3) electrical equipment; and (4) furniture and miscellaneous.

Table 4.2 Unit Root Test – Total Factor Productivity

NAICS Code	Description	Canada (x_{it})				United States (x_{it}^*)			
		No Trend		Trend		No Trend		Trend	
		μ	lag	μ	lag	μ	lag	μ	lag
311, 312	Food, beverage, and tobacco	-0.798	2	-2.021	2	-4.327***	1	-4.446***	1
313, 314	Textiles	-1.177	1	-2.017	1	0.545	2	-1.704	2
315, 316	Apparel and leather products	-1.374	2	-1.677	2	1.125	1	-1.059	1
321	Wood products	0.167	1	-1.335	1	-1.136	1	-1.109	1
322, 323	Paper and printing products	-0.789	1	-1.421	1	-0.771	1	-0.997	1
324	Petroleum and coal products	-1.023	1	-1.681	1	-0.722	2	-2.256	2
325	Chemical products	-0.707	1	-1.880	1	-1.553	1	-1.744	1
326	Plastics and rubber products	-1.331	1	-2.084	1	-0.468	1	-2.322	1
327	Non-metallic mineral products	-1.309	1	-1.795	1	-1.186	1	-1.292	1
331	Primary metal	-0.213	1	-2.225	1	-1.465	1	-1.703	1
332	Fabricated metal	-1.282	1	-1.647	1	-2.974***	1	-3.211*	1
333	Machinery	-0.894	2	-3.648**	1	-1.024	1	-1.373	1
334	Computer and electronic products	-1.318	2	-1.933	2	0.963	2	0.256	1
335	Electrical equipment	-2.076	1	-2.097	1	-0.950	1	-1.526	1
336	Transportation equipment	-0.334	2	-1.861	2	-1.840	1	-1.899	1
337, 339	Furniture and miscellaneous	-1.018	1	-0.784	1	1.738	1	-0.342	1
31-33	Manufacturing	-0.625	1	-2.033	1	0.507	1	-1.368	2

Note: Sample is 1987-2010. μ is the Elliot, Rothenberg, and Stock (1996) Dickey-Fuller statistic for the null hypothesis of a unit root using GLS estimation of the deterministic component. Lag length is chosen using Ng and Perron's (2000) modified AI criteria. Two test regressions are considered: the former includes constant and no time trend whereas the latter also includes time trend. The notation *, ** and *** denotes significant at 10%, 5%, and 1% significance level, respectively, using critical values taken from Cheung and Lai (1995) as reported in *Stata 11*.

Table 4.3 Unit Root Test – Total Factor Productivity Growth

NAICS Code	Description	Canada Δx_{it}		United States Δx_{it}^*	
		μ	lag	μ	lag
311, 312	Food, beverage, and tobacco	-6.049***	1	-4.589***	1
313, 314	Textiles	-2.488*	1	-2.883***	2
315, 316	Apparel and leather products	-1.839	2	-0.979	1
321	Wood products	-2.285*	1	-2.374*	1
322, 323	Paper and printing products	-1.885	1	-1.993	2
324	Petroleum and coal products	-1.630	2	-4.204***	1
325	Chemical products	-2.794***	1	-1.420	2
326	Plastics and rubber products	-2.991***	1	-3.588***	1
327	Non-metallic mineral products	-3.066***	1	-1.794	2
331	Primary metal	-2.303*	2	-2.993***	1
332	Fabricated metal	-2.247*	2	-3.156***	1
333	Machinery	-3.922***	1	-1.476	2
334	Computer and electronic products	-3.962***	1	-2.346*	1
335	Electrical equipment	-3.946***	1	-1.929	2
336	Transportation equipment	-2.584**	2	-1.918	2
337, 339	Furniture and miscellaneous	-1.728	2	-1.260	1
31-33	Manufacturing	-2.962***	1	-2.190*	1

Note: Sample is 1987-2010. μ is the Elliot, Rothenberg, and Stock (1996) Dickey-Fuller statistic for the null hypothesis of a unit root using GLS estimation of the deterministic component. Lag length is chosen using Ng and Perron's (2000) modified AI criteria. Test regressions include a constant and no time trend. The notation *, ** and *** denotes significant at 10%, 5%, and 1% significance level, respectively, using critical values taken from Cheung and Lai (1995) as reported in *Stata 11*.

The mixed results for the unit root tests are potentially problematic, though these results have some qualifications. First, the data structures influence the unit root test results. The sampled series are relatively small, with a 23-year horizon in growth rates. Yet the data series cover three recessions (early 1990s, early 2000 and 2007-2008), adding considerable variability not only to a small time horizon but also to individual TFP performances. Second, the presence of any structural break may lead to lower likelihood of the rejection of unit root. For example, the growth rates surge at the end of sampled period in US industries of apparel and leather and furniture and miscellaneous products. Although the results are not entirely satisfactory, the subsequent VAR analysis treats TFP growth rates as stationary.

4.4.2 Long-Run Convergence

As noted previously, the study accounts for two possible scenarios of long-run convergence: unit elasticity and non-unit elasticity. In other words, it considers a restricted cointegrating vector in the former and an unrestricted vector in the latter. It is worth bearing in mind that in both scenarios the focus is to test the null hypothesis of a stationary process against the alternative of a non-stationary process instead of a trend stationary process. This is similar to the model of technology diffusion specified in Bernard and Jones (1996a), which tests whether relative total factor productivity levels are stationary around a non-zero mean rather than a time trend. Table 4.4 summarizes these results by industry and by sector.

The left panel reports the tests for restricted cointegrating vectors. Under the null hypothesis the TFP differentials have a unit root while under the alternative the TFP differentials are stationary, supporting long-run convergence. As in Tables 4.2-4.3, DF-GLS test statistics are reported with the lag length chosen by the modified AIC. The results are fairly clear: one cannot reject the unit root null at the 10 percent level or lower. These results are consistent with Bernard and Jones (1996b), which argues that "… in the tradable-goods sector, comparative advantage leads to specialization … (p.1237)".

Table 4.4 Cointegration Tests

NAICS Code	Description	CI: $x_{it} - x_{it}^*$			CI: $x_{it} - \beta x_{it}^*$		
		μ	lag	C.V. [5%, 10%]	τ	lag	C.V. [5%, 10%]
311, 312	Food, beverage, and tobacco	-1.216	2	[-2.450, -2.116]	-1.535	1	[-2.998, -2.639]
313, 314	Textiles	0.331	2		-2.269	1	
315, 316	Apparel and leather products	0.448	1	[-2.513, -2.175]	-1.867	1	
321	Wood products	-1.007	1		-0.441	1	
322, 323	Paper and printing products	-1.236	1		-0.995	1	
324	Petroleum and coal products	-0.466	2		-0.959	1	
325	Chemical products	-0.486	1		-1.049	1	
326	Plastics and rubber products	-1.620	1		-1.873	1	
327	Non-metallic mineral products	-0.837	1		-1.129	1	
331	Primary metal	-0.713	1		-1.185	1	
332	Fabricated metal	-1.606	1		-1.529	1	
333	Machinery	-1.629	1		-1.439	1	
334	Computer and electronic products	1.177	1		-2.568	1	
335	Electrical equipment	-1.150	1		-2.896*	1	
336	Transportation equipment	-0.785	2		-1.317	1	
337, 339	Furniture and miscellaneous	1.030	1		-0.980	1	
31-33	Manufacturing	0.509	1		-1.289	1	

Note: Sample is 1987-2010. μ is the Elliot, Rothenberg, and Stock (1996) Dickey-Fuller statistic for the null hypothesis of a unit root using GLS estimation of the deterministic component. Lag length is chosen using Ng and Perron's (2000) modified AI criteria. Test regressions include a constant and no trend. The notation * denotes significant at 10% significance level, using critical values taken from Cheung and Lai (1995) as reported in *Stata 11*.

τ denotes the Engle-Granger test for the null hypothesis of no cointegration. This is the ADF test with lag order one on the residuals of the estimated cointegrating vector. Critical values are from MacKinnon (2010) using Schaffer's (2010) *Stata* code.

The tests for unrestricted cointegrating vectors are reported in the right panel of Table 4.4. For each industry, the Engle-Granger test statistic, denoted τ, for the null hypothesis that the residuals are stations is reported. For all industries, one cannot reject the null that the residual series have a unit root at the 10 percent significance level, favouring no long-run cointegration. With little evidence on convergence, the remaining analysis focuses on the growth rates rather than the levels in TFP.

4.4.3 Industry Dynamics

The analysis on industry interdependence of productivity uses simple bivariate structural VAR models for each of the sixteen industries and manufacturing as a whole. The model examines the effects of orthogonalized US TFP growth shocks on the Canadian industries using a recursive order as specified in equation (4.1). For each industry the lag order for the VAR is set to one, which is sufficient to remove any serial correlation in the innovations. All the eigenvalues lie inside the unit circle, providing further evidence that the stability condition is satisfied with the one-lag specification (Table 4.5).

The results for VAR models are summarized in Table 4.6 and Figures 4.5-4.6. The figures illustrate the cumulative response of Canadian TFP growth by industry to a one standard deviation US productivity shock, the sizes of which are reported in Table 4.6.[39] Cumulative responses in Canadian industries, if any, occur within the first two years. This is consistent with what is observed in Chapter 2 using labour productivity; US shocks pass through their Canadian counterparts fairly quickly. However, fewer industries now feel the impact from the US compared to the analysis on labour productivity. In particular, the immediate effect from the US shocks, previously observed in computer and electronics, electrical equipment, and furniture and miscellaneous, no longer occurs in the analysis here.

[39] The standard error bands in the figures and the shaded numbers in the tables denote statistically significant response at 68% level. For small-sample confidence interval for impulse responses function a classical 90% or 95% band can provide misleading information (Sims and Zha, 1999).

Table 4.5 Modulus of Complex Eigenvalue post VAR Estimation

NAICS Code	Description	Modulus of Eigenvalue			
		Δx_{it}^*		Δx_t^*	
311, 312	Food, beverage, and tobacco	0.307	0.307	0.175	0.172
313, 314	Textiles	0.474	0.231	0.172	0.017
315, 316	Apparel and leather products	0.637	0.493	0.466	0.202
321	Wood products	0.386	0.386	0.281	0.281
322, 323	Paper and printing products	0.367	0.124	0.239	0.239
324	Petroleum and coal products	0.164	0.164	0.159	0.159
325	Chemical products	0.292	0.144	0.171	0.171
326	Plastics and rubber products	0.529	0.365	0.518	0.136
327	Non-metallic mineral products	0.108	0.061	0.151	0.028
331	Primary metal	0.302	0.261	0.393	0.393
332	Fabricated metal	0.179	0.001	0.126	0.021
333	Machinery	0.403	0.189	0.354	0.354
334	Computer and electronic products	0.432	0.109	0.375	0.008
335	Electrical equipment	0.382	0.078	0.378	0.378
336	Transportation equipment	0.228	0.060	0.241	0.146
337, 339	Furniture and miscellaneous	0.389	0.260	0.098	0.098
31-33	Manufacturing	0.370	0.173	0.370	0.173

Note: One lag length is considered in estimating VAR. Growth measures in US total factor productivity considered include Δx_{it}^* by industry and Δx_t^* by sector. For complex eigenvalues modulus is $r + ci$ calculated as $\sqrt{r^2 + c^2}$. The VAR is stable if the modulus of each eigenvalue of eigenvalue matrix is strictly less than 1 (Lutkepolh, 2005 and Hamilton, 1994).

Table 4.6 Cumulative Impulse Response Functions and Forecast Error Variance Decompositions

NAICS Code	Description	US Shocks	Cum. Response (s.e.) Step 1		Cum. Response (s.e.) Step 8		FEVD Step 1	FEVD Step 8
311, 312	Food, beverage, and tobacco products	0.058	0.001	(0.009)	0.003	(0.008)	0.051	0.083
313, 314	Textile mills and textile product mills	0.101	-0.008	(0.014)	-0.004	(0.014)	0.124	0.336
315, 316	Apparel and leather and allied products	0.080	-0.030	(0.028)	-0.057	(0.078)	0.079	0.395
321	Wood products	0.063	0.026	(0.017)	0.039	(0.029)	0.048	0.150
322, 323	Paper and printing	0.053	0.014	(0.014)	0.014	(0.017)	0.150	0.138
324	Petroleum and coal	0.191	-0.053	(0.040)	-0.051	(0.039)	0.038	0.072
325	Chemical products	0.063	-0.009	(0.016)	-0.008	(0.016)	0.001	0.049
326	Plastics and rubber products	0.057	0.036	(0.016)	0.040	(0.022)	0.134	0.252
327	Non-metallic mineral products	0.071	0.046	(0.021)	0.047	(0.022)	0.348	0.353
331	Primary metals	0.089	0.007	(0.018)	0.008	(0.021)	0.126	0.286
332	Fabricated metal products	0.058	0.020	(0.015)	0.021	(0.013)	0.320	0.333
333	Machinery	0.081	0.019	(0.026)	0.017	(0.031)	0.258	0.272
334	Computer and electronic products	0.105	0.016	(0.041)	-0.041	(0.067)	0.304	0.420
335	Electrical equipment	0.075	-0.009	(0.024)	-0.013	(0.021)	0.103	0.147
336	Transportation equipment	0.081	0.014	(0.020)	0.014	(0.023)	0.072	0.071
337, 339	Furniture and miscellaneous	0.043	-0.013	(0.016)	-0.016	(0.023)	0.007	0.041
31-33	Manufacturing	0.040	0.027	(0.012)	0.028	(0.017)	0.492	0.458

Note: Variance-covariance matrix is degree-of-freedom adjusted for small samples. The US shocks reported above are one standard deviation of US shocks by industry. Shaded numbers are statistically significant using the 68% confidence intervals reported in Figures 4.5 and 4.6.

Figure 4.5 Response of Canadian TFP to One S.D. US TFP Shock, by Industry and Sector (68% CI; Relative Importance in Parentheses)

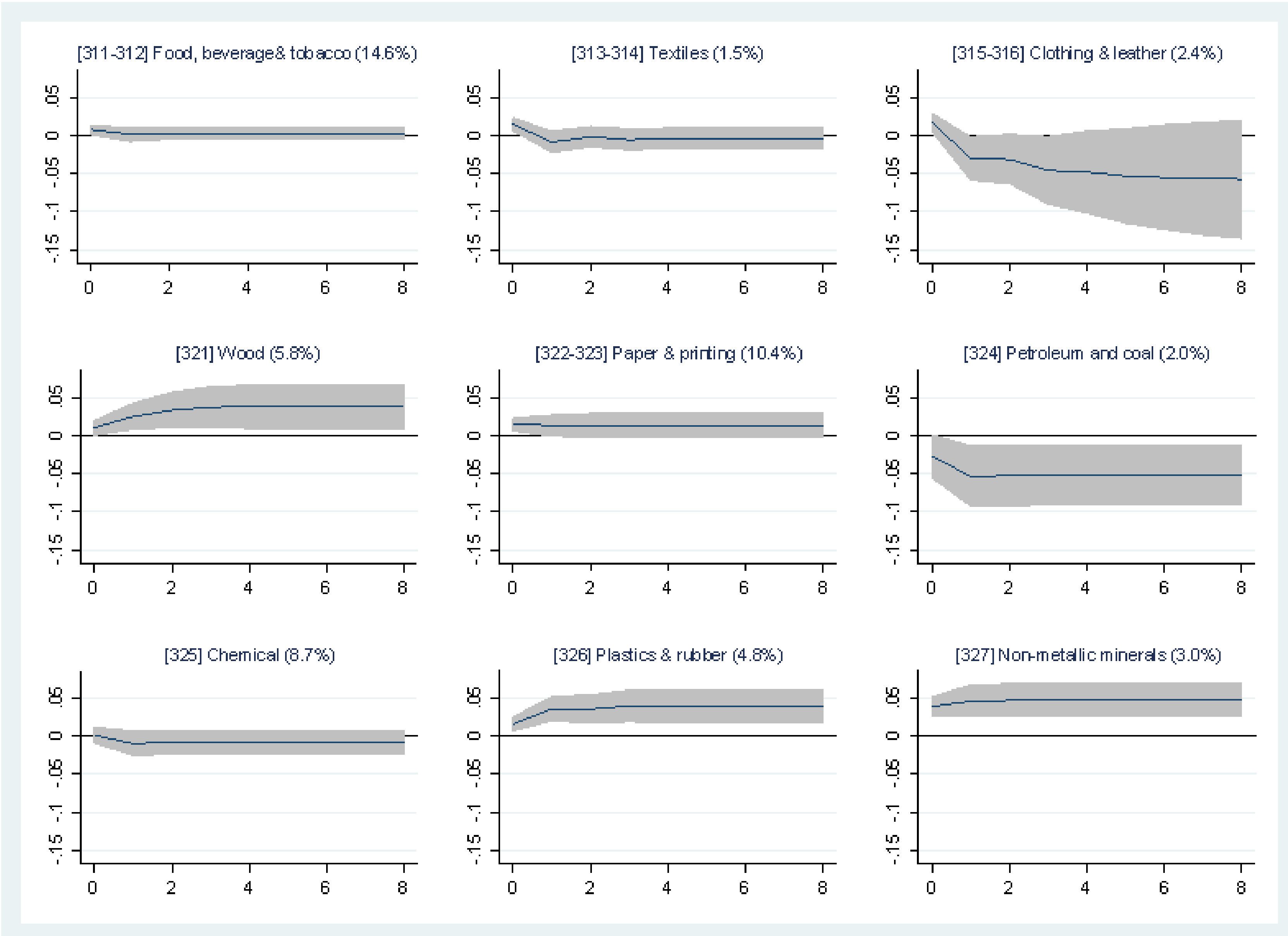
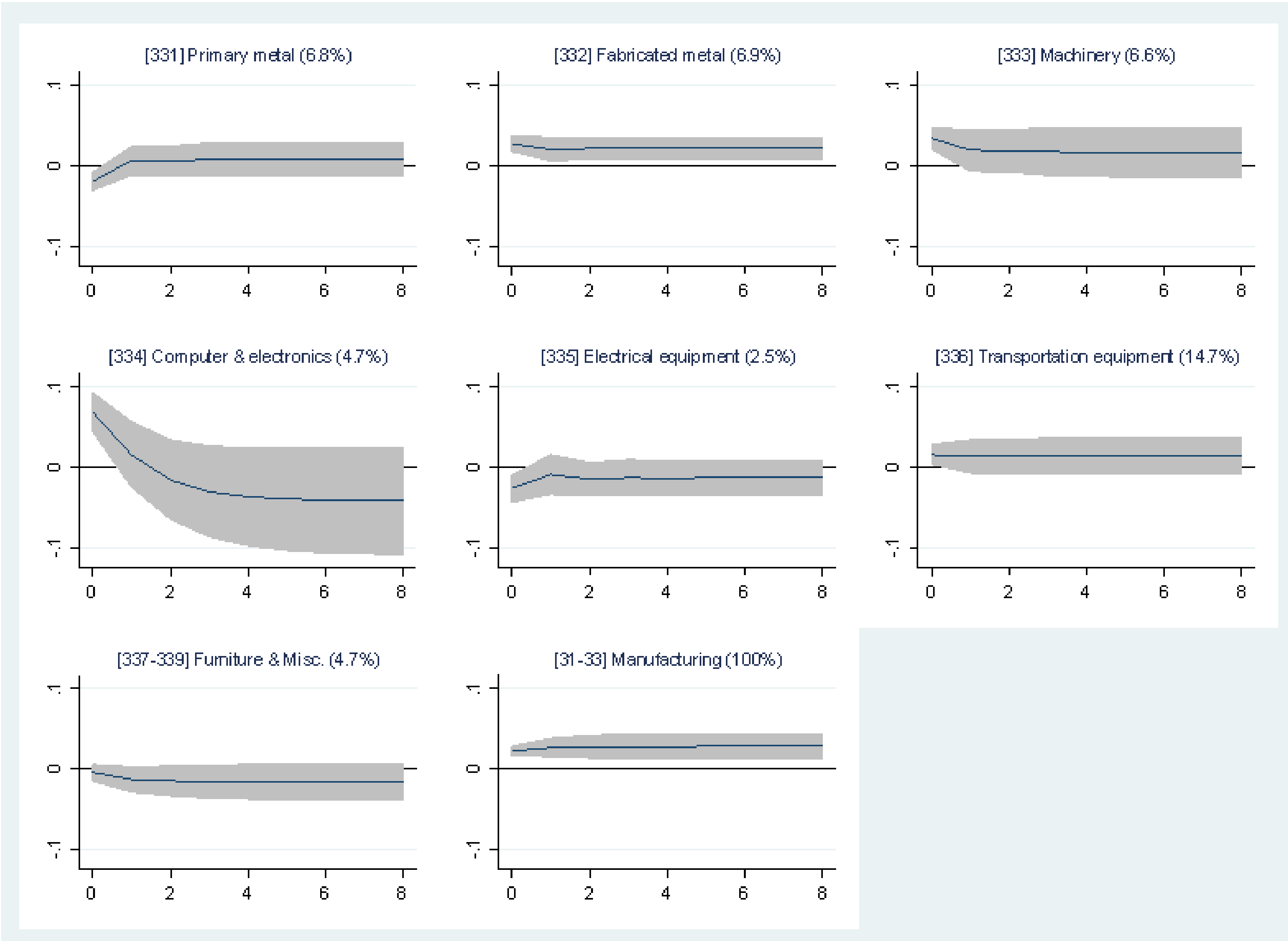


Figure 4.6 **Response of Canadian TFP to One S.D. US TFP Shock, by Industry and Sector (68% CI; Relative Importance in Parentheses)**



Four industries experience positive and permanent responses to US productivity shocks. These are (1) wood; (2) plastics and rubber; (3) non-metallic minerals; and (4) fabricated metal. In these industries the long-run effects of US productivity shocks are of fair size; the standardized responses in Canadian TFP growth vary from 0.4 to 0.7 percent to a one-percent standardized US productivity shock. These responses, as expected, suggest a significant amount of dependence in Canadian industries on their US counterparts. It is worth noting that all these industries (except plastics and rubber) have high average growth in TFP relative to their US counterparts. In response to an increase in US productivity shocks, it appears Canadian industries raise productivity, either by innovation or improved organizational methods, to increase their immediate and subsequent competitiveness.

Petroleum and coal exhibits negative and permanent response to US productivity shocks; a one-percent standardized US shock reduces standardized Canadian TFP growth by 0.3 percent. The result is quite puzzling. The VAR model captures this opposing growth pattern yet does not shed light on its underlying forces. At most, the current model suggests that Canadian petroleum and coal industries are very distinct from their US counterparts. One advantage of studies, such as conducted in this chapter, is that it highlights industries that are significant outliers and warrant closer examination.

For apparel and leather, the US productivity shocks do not demonstrate any long-run impact despite the initial positive effect. This initial positive response alters direction in the subsequent years. Trade liberalization since 1970s has reshaped Canadian clothing market drastically, particularly since the introduction of Canada-US Free Trade Agreement as well as the Uruguay Rounds of negotiations with WTO countries around the 1990s. Domestic demand for imported clothing has increased dramatically while both domestic and the US demand for Canadian produce have declined over time, resulting in a shrinking clothing industry facing rising international competition (Boyer, 1999, and Wyman, 2005). The combination of declining domestic demand and shrinking industry size may likely contribute to slow or little adaption to US productivity shocks.

Two individual industries do not at all respond to US productivity shocks, in either the short or the long run. They are (1) chemical; and (2) furniture and miscellaneous. It is interesting to conjecture what might underlie these zero dependence. Both industries in Canada suffer from a decline in average TFP growth rates in contrast to an increase in their US counterparts post 2000 (see Tables A3.2 and A3.3 for a comparison). It is possible that Canadian industries become less competitive (e.g., due to the unwillingness to shed labour that reinforces further declines in productivity).

The remaining industries, eight in total, demonstrate some contemporary response. However, these initial responses do not have a long run impact on Canadian productivity growth. They are (1) food, beverage and tobacco; (2) textiles; (3) paper and printing; (4) machinery; (5) computer and electronics; (6) transportation equipment; (7) primary metals; and (8) electrical equipment. Moreover, the responses are non-uniform. Despite the insignificant responses in both the short and long run, five of these industries have consistent responses throughout the course of eight years ahead. They are (1) food, beverage and tobacco; (2) paper and printing; (3) machinery; (4) transportation equipment; and (5) electrical equipment. In contrast, the three remaining industries alter their responses in an opposite direction after the initial response. Although it might be difficult to explain these insignificant responses, the results for these industries certainly suggest that there is no pressure on Canadian TFP from interaction with US counterparts.

At the sector level, a one-percent standardized US productivity shock gives rise to an immediate and significant increase of 0.7 percent in Canadian TFP standardized growth. This initial response remains significant and increases slightly in the long run (eight years). In other words, a one-percent US innovation shock raises Canadian TFP growth by 0.7 percent permanently in manufacturing as a whole. This sectoral response is of a comparable size to the largest response observed by the individual industrial investigation. The discrepancy in responses between individual industries and the sector have two relevant implications. First, inter-industry as opposed to intra-industry, dynamics may play a more important role that might be captured by an investigation at a more aggregate level, say, at the sectoral level. This possibility will be discussed further in the following context. Second, a common demand shock associated with business cyclical variation may be a more dominate factor in industrial dynamics than technology transfer.

An indication of the relative importance of US productivity shocks for Canadian TFP can be drawn by examining the forecast error variance decomposition (FEVD). These are reported in Table 4.6, for both the one-step and eight-step ahead forecast. For brevity, the discussion focuses on the eight-step horizon which is a reasonable approximation of the variance of Canadian TFP growth (Hamilton, 1994). Despite the lack of evidence from individual industrial responses, for nine industries almost half of the variance in Canadian TFP growth can be attributed to their US counterparts.

The industry with the largest US contribution is computer and electronics; 42 percent of its variation in Canadian TFP growth stems from US productivity shocks. The next largest contribution of US shocks is to the apparel and leather industries despite its zero long-run direct impact. For industries of non-metallic mineral and fabricated metal products, US productivity shocks account for over 30 percent of the variation in Canadian TFP growth. This further suggests the dependence of Canadian manufacturing on its US counterpart. Although the impulse response functions do not demonstrate long-run association to a large extent as they do on productivity levels, the US effects are an importance source of shocks for Canadian productivity growth rates.

The lack of evidence in the impulse response by individual industry, along with the significant amount of dependence on US shocks, provides a different angle to tackle the puzzle. Since individual US shocks by industry do not seem to have an uniform impact on Canadian industries, it is natural to ask whether there is a force of some sort at an aggregate level that does. Table 4.7 and Figures 4.7-4.8 attempt to answer the question by considering the US shocks at the sector level. The resulting individual responses are more consistent with the conventional wisdom that productivity shocks south of the border promote productivity improvement through technology transfer or adaption and improved competitiveness as a result in Canadian industries.

Eight industries experience positive and permanent responses to TFP shocks in US manufacturing. They are (1) textiles; (2) non-metallic mineral; (3) primary metals; (4)

fabricated metal; (5) machinery; (6) electrical equipment; (7) transportation equipment; and (8) furniture and miscellaneous. In some industries, despite a zero permanent effect there appears to be more immediate positive responses, including (1) paper and printing; (2) chemicals; and (3) computer and electronics. Petroleum and coal once again exhibits a negative and permanent response to US manufacturing shocks. Only two industries do not demonstrate any response at all, in either the short or long run. They are (1) food, beverage and tobacco; and (2) apparel and leather.

In the eight-step horizon of FEVD shown in Table 4.7, US contribution to the variation in Canadian TFP growth is significant in a large number of individual industries. The industry with the largest US contribution is primary metal; 50 percent of its variation in TFP growth can be explained by US productivity shocks. As noted earlier, US manufacturing shocks may simply reflect the cyclical variance in demand originated from the US. As business cycle peaks in the US market demand rises domestically (Rao and Li, 2013). It is likely that this type of procyclical demand shock puts upwards pressure on Canadian industries to improve their productivity. This, however, is beyond the scope of the current analysis.

Although non-uniform, the evidence of positive and permanent responses from Canadian industries indicates the significant dependence of Canadian TFP on the US manufacturing. This in turn suggests that a better understanding of the means by which these productivity measures are related may be useful for a better understanding of Canadian TFP growth. Further, while US productivity shocks appear to be important, the direction of the effect is never uniform across industries. The next chapter provides a preliminary attempt to determine what industry-specific features might contribute to these relationships.

Table 4.7 Cumulative Impulse Response Functions and Forecast Error Variance Decomposition

NAICS Code	Description	US Shocks	Cum. Response (s.e.) Step 1		Step 8		FEVD Step 1	Step 8
311, 312	Food, beverage, and tobacco products	0.040	0.000	(0.010)	-0.001	(0.011)	0.009	0.015
313, 314	Textile mills and textile product mills	0.040	0.026	(0.017)	0.025	(0.019)	0.304	0.304
315, 316	Apparel and leather and allied products	0.040	-0.013	(0.018)	-0.009	(0.017)	0.015	0.105
321	Wood products	0.040	0.023	(0.017)	0.019	(0.022)	0.296	0.284
322, 323	Paper and printing	0.040	0.009	(0.015)	0.006	(0.019)	0.091	0.094
324	Petroleum and coal	0.040	-0.090	(0.041)	-0.088	(0.049)	0.023	0.267
325	Chemical products	0.040	0.012	(0.018)	0.011	(0.024)	0.059	0.057
326	Plastics and rubber products	0.040	0.023	(0.017)	0.016	(0.030)	0.305	0.249
327	Non-metallic mineral products	0.040	0.051	(0.022)	0.055	(0.029)	0.192	0.291
331	Primary metals	0.040	0.059	(0.019)	0.062	(0.026)	0.394	0.501
332	Fabricated metal products	0.040	0.031	(0.016)	0.032	(0.018)	0.316	0.321
333	Machinery	0.040	0.059	(0.025)	0.070	(0.037)	0.260	0.354
334	Computer and electronic products	0.040	0.027	(0.051)	0.019	(0.066)	0.081	0.085
335	Electrical equipment	0.040	0.027	(0.026)	0.028	(0.028)	0.000	0.118
336	Transportation equipment	0.040	0.040	(0.021)	0.040	(0.027)	0.353	0.343
337, 339	Furniture and miscellaneous	0.040	0.018	(0.016)	0.019	(0.019)	0.088	0.096
31-33	Manufacturing	0.040	0.027	(0.012)	0.028	(0.017)	0.492	0.458

Note: Variance-covariance matrix is degree-of-freedom adjusted for small samples. The US Shocks reported above are one standard deviation of US shock by manufacturing sector as a whole. Shaded numbers are statistically significant using the 68% confidence intervals reported in Figures 4.5 and 4.6.

Figure 4.7 Response of Canadian TFP to One S.D. US Manufacturing TFP Shock, by Industry and Sector (68% CI, Relative Importance in Parentheses)

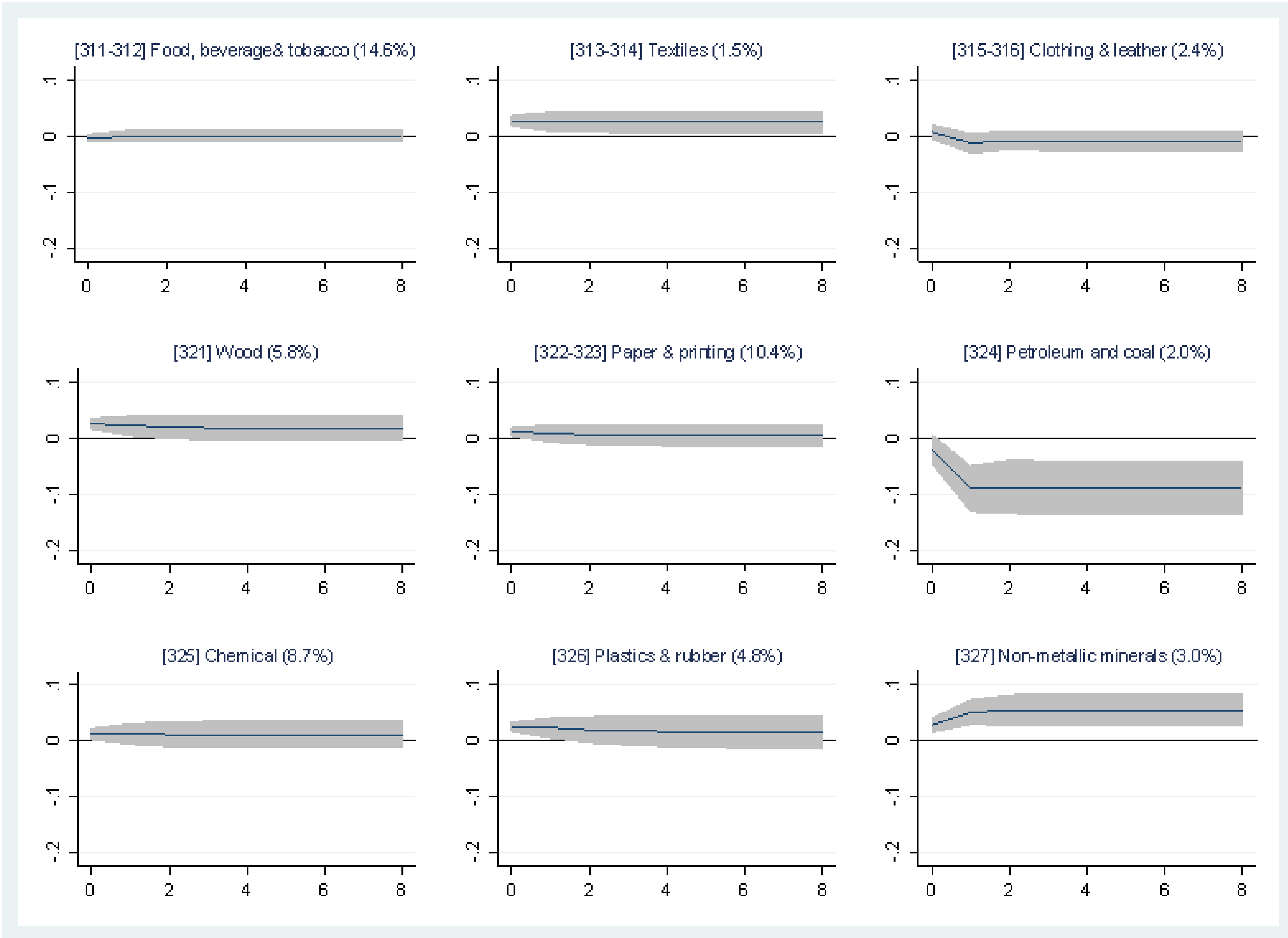
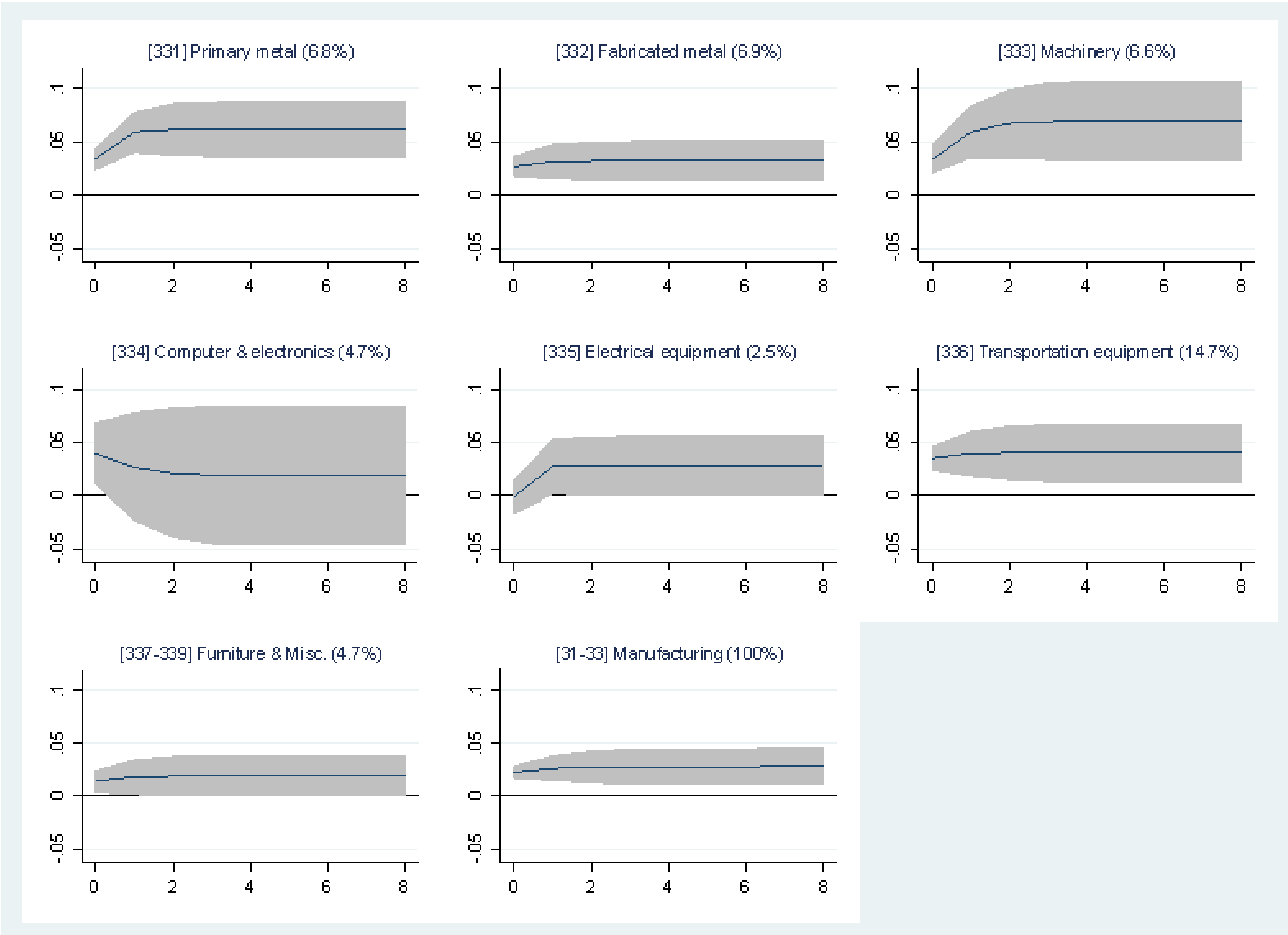


Figure 4.8 Response of Canadian TFP to One S.D. US Manufacturing TFP Shock, by Industry and Sector (68% CI, Relative Importance in Parentheses)



4.5 Conclusions

The current analysis examines the empirical relationships between total factor productivity (TFP) for US and Canadian industries in both the short and long run. It is well known that Canadian industries lag US industries in productivity, in levels as well as in growth rates. This analysis is designed to see the extent US productivity innovations are transmitted into Canadian counterpart on an industry basis.

With no evidence of convergence in TFPs between Canadian and US manufacturing industries, the chapter takes a purely empirical perspective and look at each industry in isolation. It seeks to identify the extent to which US productivity growth shocks feed through into Canadian TFP levels and growth rates. The answer is twofold. If US shocks are considered by industry the feeding through is somewhat limited and not uniform in the short run while becoming less influential in the long run for the majority of manufacturing industries. If US shocks are considered by sector, the impact in both the short and long run becomes more positive and feeds through to a greater number of Canadian industries. Indeed, one might anticipate the productivity relationship to be swamped by business cycle correlations. This cyclical effect does appear - from the latter case - at a more aggregated level.

The chapter points to a potential direction for future study. Industry characteristics, such as international trade and R&D, may facilitate the productivity pass-through from the US to Canada. One may further identify how industry dependence, where a dynamic relation exists, is intermediated by industry-specific features. This is considered in the next chapter.

Appendix Table

Table A4.1 Unit Root Test – Total Factor Productivity Growth

NAICS Code	Description	Canada (Δx_{it})		United States (Δx_{it}^{*})	
		μ	lag	μ	lag
311, 312	Food, beverage, and tobacco	-6.079***	1	-4.798***	1
313, 314	Textiles	-2.650	1	-6.190***	1
315, 316	Apparel and leather products	-1.800	2	-1.898	1
321	Wood products	-2.502	1	-3.914***	1
322, 323	Paper and printing products	-1.981	1	-3.231*	1
324	Petroleum and coal products	-2.184	2	-4.658***	1
325	Chemical products	-3.120*	1	-1.603	2
326	Plastics and rubber products	-3.058	1	-3.770***	1
327	Non-metallic mineral products	-2.926	1	-3.347*	1
331	Primary metal	-2.237	2	-3.464**	1
332	Fabricated metal	-2.259	2	-3.479**	1
333	Machinery	-3.927***	1	-3.123*	1
334	Computer and electronic products	-4.175***	1	-2.323	1
335	Electrical equipment	-4.021***	1	-2.034	2
336	Transportation equipment	-5.211***	1	-3.435*	1
337, 339	Furniture and miscellaneous	-3.015	1	-2.177	1
31-33	Manufacturing	-3.023	1	-3.891***	1

Note: Sample is 1987-2010. μ is the Elliot, Rothenberg, and Stock (1996) Dickey-Fuller statistic for the null hypothesis of a unit root using GLS estimation of the deterministic component. Lag length is chosen using Ng and Perron's (2000) modified AI criteria. Test regressions include a constant and a time trend. The notation *, ** and *** denotes significant at 10%, 5%, and 1% significance level, respectively, using critical values taken from Cheung and Lai (1995) as reported in *Stata 11*.

Chapter 5 Cross-Border Technology Diffusion: Evidence from Total Factor Productivity in Canada-U.S. Manufacturing

"… What is the geographic scope of technical progress? One camp holds that by its very nature technology is freely available everywhere. … At the other extreme, the new growth theory typically relates a country's technical advances to only its own innovations. … In contrast to either polar position, economic historians describe world growth in terms of the gradual diffusion of advances from a small set of innovators. Innovative countries are the most productive, but their innovations also drive growth elsewhere."

Eaton and Kortum (1999 p.537-538)

5.1 Introduction

The previous chapter finds little evidence for long-run convergence in productivity within manufacturing between Canada and the US, and further finds that there is non-uniform transmission of productivity innovation within industries across borders. This chapter seeks to quantify the extent to which Canadian manufacturing industries depend upon their US counterparts, and how such industry dependence, where innovation transmission exists, is determined by industry characteristics.

Specifically, this chapter examines the extent of interdependence in a panel data set for Canadian and US manufacturing industries from 1987-2010. The data set is constructed to ensure comparability of Canadian and US productivity measures following the principles explained in Chapter 3. To identify whether individual industry characteristics facilitate the productivity diffusion process, the paper develops a dynamic panel regression model analogous to Cameron, Proudman and Redding's (2005) study for the UK and the US.[40] The analysis examines the roles played by the industry intensities of exports, imports, foreign direct investment (FDI), and research and development (R&D) -

[40] As well, the model is similar in principle to that in Chapter 2 for Canada and the US on labour productivity.

identified in the literature as characteristics likely to support technology transfer and diffusion (e.g., Eaton and Kortum, 1999, Keller, 2004 and Aghion and Howitt, 2005).

Two main findings emerge from the study. First, the panel estimation suggests that on average US productivity innovations have a contemporaneous and positive impact on Canadian productivity growth. Moreover, industry-specific characteristics are found to be important channels for technology diffusion. In particular, a positive dependence on US productivity innovations is found in the short run through export, import, and FDI intensities. Surprisingly, though, a higher R&D intensity reduces the short-run technology diffusion in most manufacturing industries, possibly suggesting a substitutive role of domestic R&D activities for innovation transmission from the US.

Second, estimates of the long-run effects implied by the panel models reveal that technology diffusion from the US is positive yet non-uniform across industries after controlling for industry-specific characteristics. Compared to its impact on Canadian manufacturing in the short run, technology diffusion is found in fewer industries in the long run. Despite the asymmetry in transmission pattern, two industries are common wherein all industry measures considered facilitate the long-run diffusion process: plastics and rubber, and primary metal. Little evidence of long-run technology diffusion in the remaining industries coincides with the lack of evidence on industrial convergence identified in Chapter 4.

The remainder of the chapter is structured as follows. Section 5.2 introduces the industry characteristics and lays out the empirical framework. Section 5.3 discusses the data development and summary statistics. Section 5.4 presents the empirical analysis, followed by conclusions in Section 5.5.

5.2 Empirical Framework

5.2.1 Technology Diffusion and Industry Characteristics

The analysis in this chapter examines the extent to which productivity innovation diffuses from the US to Canada in manufacturing industries and whether certain industry characteristics facilitate such diffusion. The question of interest is examined on an industry-by-industry basis rather than at the sector level; both the asymmetry in technology diffusion pattern (e.g., Keller, 2004, Helpman, 2006 and Acharya and Keller, 2009) and the variations of industrial productivity within Canadian manufacturing (Baldwin and Macdonald, 2009) suggest that an investigation at the industry level is more suitable.

The first three industry characteristics are measures of openness to and integration with the US economy: export, import and foreign direct investment (FDI) as shares of industry production. Trade (export and import) and FDI expose economic entities to a larger market that motivates the adoption of new technologies (Helpman, Melitz and Yeaple, 2004, and Keller, 2009).[41] The trade-investment linkages within industries may also provide direct exposure to new practices and/or technologies. Moreover, imports may help transfer the embodied technology in intermediate goods from foreign countries (e.g., Grossman and Helpman, 1991; Acharya and Keller, 2009). In short, higher trade and FDI intensities may act as a proxy for more competitive industries whereby strong incentives persist to adopt productivity advancement.

The final industry characteristic is research and development (R&D) expenditure as a share of industry production. Industries with high levels of R&D expenditure are likely those to be competitive and open to adopt new technologies. These industries not only seek new solutions but also "understand and evaluate new technological trends and innovations" (Keller, 2004 p.774). As well, R&D expenditure may reflect expenditure necessary within industries to adopt new technologies, possibly from foreign competitors. Implementing new technologies may require complementary skills that may be costly to acquire for efficient operation (Aghion and Howitt, 2005). R&D expenditure therefore may proxy for "absorptive capacity" in competitive industries that strive to stay fit by innovating and adopting new technologies.

[41] The learning-by-exporting argument suffers from a chicken-or-the-egg dilemma, whether more productive firms are those that export or whether firms subsequently become more productive when exposed to a larger market and thereby enhanced competiveness. Regardless, exporting firms are found to be more productive than non-exporting firms in case studies (e.g., Bernard and Jensen, 1999).

5.2.2 Dynamic Panel Models of Total Factor Productivity and Industry Characteristics

Prior to modelling the empirical relationships amongst Canadian and US manufacturing industries, it is useful to have a simple theoretical framework wherein the rest of the discussion can be carried out properly. Two seminal empirical papers that provide a simple framework for modelling technology diffusion are Bernard and Jones (1996a, b). Underlying this framework is the basic idea from standard growth theory, which predicts unconditional convergence from technology transfer whereby a sector in productivity-backward countries catches up with that sector in more innovative countries. Following this reasoning, the distance in productivity level from the frontier country, or productivity gap, is used to model any potential catch-up effect (for more examples, see Aghion and Howitt, 2005).

As noted previously, Cameron *et al*. (2005) applies this framework to an analysis of UK and US productivity in manufacturing industries similar to the focus here. In general terms, their framework amounts to a dynamic panel model of domestic industry productivity growth rates dependent upon foreign industry productivity growth as well as industry productivity gaps; in effect, the productivity gaps serve as error correction terms in their model of industry productivity growth. A key focus of Cameron *et al*.'s analysis is how the catch-up terms (i.e., the coefficients on the error correction terms) interact with specific industry characteristics, similar to those discussed in the previous section. Their approach, following the convergence literature, relies on long-run relationships in productivity levels. A key contribution of this paper is sorting out these long-run relationships for Canadian and US manufacturing industries.

The chapter follows the same notation as the previous chapter. For industry *i* at time *t*, domestic and foreign total factor productivity (TFP) growth (in log first differences) are denoted as Δx_{it} and Δx_{it}^{*}, respectively. Canadian productivity growth for industry *i* at time *t* is now modelled as:

$$\Delta x_{it} = \beta_0 + \beta_{i1}\Delta x_{it}^{*} + \beta_{i2}\Delta x_{it-1}^{*} + \beta_3 \Delta CU_{it} + \beta_{i4}\Delta x_{it-1} + \varepsilon_{it}$$

for $t = 2 \ldots T$ and $i = 1 \ldots N$ where N is the number of industries (sixteen).[42] The model assumes a single lag for the dependent variable. It also allows for industry and time fixed effects. As usual, these fixed effects can be viewed as components of ε_{it}.

I now also include a measure of capacity utilization growth, denoted as ΔCU_{it} for each Canadian industry.[43] Practically, TFP growth estimates account for the level of physical capital in place rather than in use; the level of input used in production is often not observable and difficult to measure (e.g., Gu and Wang, 2013). This introduces a pro-cyclical measurement bias in traditionally measured TFP growth that can be captured by the rate of change in capacity utilization. The results in Chapter 4, where sectoral productivity growth has sizable effects on industry productivity growth, further suggest the need to control for cyclical variation.

A potential problem arises when estimating equation (2) using fixed effect. The presence of the lagged dependent variable introduces a potential bias for the associated coefficients. The bias arises because of correlation between the lagged dependent variable and the error term in the fixed effects framework, Nickell (1981). The bias is due to the finite sample of time series observations and is likely to be particularly acute for typical microeconomic panels, which usually rely on small fixed time series samples. For larger T, as is usually assumed in macroeconomic studies such as this, the bias goes away. How large T must be for the bias to be acceptable is an open question, see for example the discussion in Judson and Owen (1996).

For purposes here, with $T = 24$, I will proceed with standard estimation and set concerns about this bias aside. The justification for this is that the coefficient on the lagged dependent variable, where the bias arises, is not directly of interest (though these coefficients do bear indirectly on some of the results discussed below). Some limited robustness checks in this regard are discussed below.

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[42] This model is similar in principle to the VAR model in Chapter 4 yet focuses exclusively on the behaviour of Canadian TFPs, treating US productivity is treated as an exogenous variable in the model.

[43] Arguably, US capacity utilization should also be included in the regression for the same reasons. However, given the close synchronization of US and Canadian business cycle, and the need to conserve degrees of freedom, the analysis relies entirely on the Canadian measure to capture cyclical variation.

To capture the possibilities that the effect of US productivity growth is dependent upon industry characteristics, I introduce each industry characteristics in isolation. The reason to do so is that the characteristics are quite highly correlated and it is difficult to estimate the model with multiple characteristics. This is especially true given the way in which the characteristics will be interacted with other variables. Let w_i denote one of the intensities for industry *i*, discussed above. The manner in which US productivity growth contributes to Canadian TFP growth is assumed to be:

$$\begin{aligned}\beta_{i1} &= \eta_1 + \delta_1 w_i \\ \beta_{i2} &= \eta_2 + \delta_2 w_i\end{aligned}$$

That is, the contribution to Canadian TFP growth from US productivity growth can be decomposed into two components: direct growth (captured by η_1 and η_2) and indirect growth through dependence upon the industry characteristic (captured by δ_1 and δ_2). Two sets of hypotheses are of interest. The first is that β_{i1} and β_{i2} are non-negative for any w_i; a rise or no change in domestic TFP growth is expected in response to US productivity growth. The second set is that the indirect effects are positive; that is, $\delta_1, \delta_2 > 0$. In other words, greater intensities are expected to give rise to greater transmission of an increase in US productivity growth to Canadian industries.

Substituting these two expressions into the dynamic panel model yields:

$$\mathbf{\Delta} x_{it} = \beta_0 + \eta_1 \mathbf{\Delta} x^*_{it} + \delta_1 w_i \mathbf{\Delta} x^*_{it} + \eta_2 \mathbf{\Delta} x^*_{it-1} + \delta_2 w_i \mathbf{\Delta} x^*_{it-1} + \beta_3 \mathbf{\Delta} CU_{it} + \beta_{i4} \mathbf{\Delta} x_{it-1} + \varepsilon_{it} \qquad (5.1)$$

After controlling for time and industry fixed effects the model further assumes that the model disturbances are serially uncorrelated within each panel and uncorrelated across panels. However, the model allows for possible heteroskedasticity across panels. Equation (5.1) is very similar in principle to the panel model estimated by Cameron *et al.* (2005) except as noted previously I do not include a lagged productivity gap (error correction term) because there is no long-run relationship between Canadian and US productivity levels.

5.2.3 Multiplier Effects

From equation (5.1), three marginal effects are considered. The first is the immediate effect on Canadian TFP growth arising from a contemporaneous, or lagged, change in US productivity growth. The second is the effect on steady-state TFP growth in Canada from a permanent change in US steady-state productivity growth. The last is the effect on steady-state TFP growth in Canada from a change in industry characteristics, evaluated at mean US productivity growth. In other words, the first two effects capture the marginal effects of US productivity innovations in the short and long run while the last marginal effect captures the long-run effect of a permanent change in industry characteristics. These effects are referred to as multiplier effects hereafter.

The short-run multipliers are simply:

$$\frac{d\mathbf{\Delta}x_{it}}{d\mathbf{\Delta}x^*_{it}} = \beta_{i1} = \eta_1 + \delta_1 w_i$$
$$\frac{d\mathbf{\Delta}x_{it}}{d\mathbf{\Delta}x^*_{it-1}} = \beta_{i2} = \eta_2 + \delta_2 w_i$$

These short-run multiplier effects capture the immediate impact on Canadian industries arising from a change in contemporaneous and lagged US productivity innovations. As discussed earlier, one would expect β_{i1} and β_{i2} to be non-negative for any industry intensities (w_i) and δ_1 and δ_2 to be positive for a facilitating role for intensities in technology transmission.

As for the long-run effect, let Δx_i and Δx_i^* denote Canadian and US steady-state TFP growth. Let ΔCU_i denote the steady-state rate of capacity utilization in Canada, which is presumably zero. The model, evaluated at steady state, becomes (setting the disturbance term to zero):

$$\mathbf{\Delta}x_i = \beta_0 + \eta_1\mathbf{\Delta}x_i^* + \delta_1 w_i\mathbf{\Delta}x_i^* + \eta_2\mathbf{\Delta}x_i^* + \delta_2 w_i\mathbf{\Delta}x_i^* + \beta_{i4}\mathbf{\Delta}x_i$$

Then the first long-run multiplier is:

$$\frac{d\mathbf{\Delta}x_i}{d\mathbf{\Delta}x_i^*} = \frac{1}{1-\beta_{i4}}\left[\eta_1 + \eta_2 + (\delta_1 + \delta_2)w_i\right]$$

The second long-run multiplier is:

$$\frac{d\mathbf{\Delta}x_i}{d\mathbf{\Delta}w_i} = \frac{1}{1-\beta_{i4}}(\delta_1 + \delta_2)\mathbf{\Delta}x_i^*$$

The first long-run multiplier captures by industry how US productivity growth transmits to Canadian productivity growth and the dependence of this transmission upon industry characteristics. On the one hand, the sign of the coefficient on the intensity interaction terms, δ_1 and δ_2, gives an indication as to how these intensities contribute to the diffusion of productivity. On the other hand, the magnitude and its statistical significance depend upon the parameter estimates of η_s for s = 1, 2 and the w_i themselves. If, the two hypotheses hold as discussed previously, one would expect an increase in US steady-state productivity growth to give rise to a permanent increase in Canadian productivity growth.

The second long-run multiplier effect highlights how industry characteristics influence the effect of US productivity growth on the Canadian counterpart, conditional on the estimated model and the level of US productivity growth. In other words, it examines the extent to which industry characteristics facilitate the technology diffusion from the US in the long run. If the second hypothesis holds as discussed earlier, one would expect that an increase in industry intensities raises the degree of innovation transmission permanently.

It is worth bearing in mind that these long-run multiplier effects are industry dependent. The internal dynamics for each industry is governed by three factors: (1) productivity growth path, or β_{i4} parameter; (2) industry intensities, w_i; and (3) the average growth in US productivity for that industry. All of these factors are industry specific.[44]

[44] These characteristics may have more general contributions to long-run growth but in the current context the contribution arises through the interaction between US productivity growth and their industry characteristics.

5.3 Data Source

The data set consists of sixteen manufacturing industries by North American Industry Classification System (NAICS) three-digit classification and manufacturing as a whole for the period 1987-2010. Data source and development on growth rates of total factor productivity for Canada and the US is detailed in Chapters 3 and 4.

The rate of capacity utilization is quarterly available for 1987-2010 from CANSIM Table 028-0002. The annual rate of capacity utilization is calculated as a four-quarter average. For further industry aggregation (e.g., [311] and [312] to [311, 312] and so forth) the proportion of industrial production is employed to calculate weights. Industry production is evaluated as real gross domestic product (GDP) and is obtained annually from CANSIM Table 383-0022 for 1986-2008. For the post-2008 period, industrial proportion uses the 2008 values.[45]

Data on domestic exports to and imports from the US are available annually in 1992-2010 and are extracted directly from Canadian Trade by Industry.[46] Export intensity is constructed as a ratio of domestic exports to the US relative to manufacturing shipments. Import intensity, similarly, is a ratio of total imports from the US relative to manufacturing shipment. These intensity measures differ from those defined by Industry Canada which measures domestic export to or import from the rest of world.

Data on FDI and R&D are available on an annual basis from CANSIM Tables 376-0052 for 1999-2010 and 358-0024 for 1994-2010, respectively. Both industry characteristics are then scaled by total manufacturing shipments, also from Canadian Trade by Industry. FDI from the US (inflow) and Canadian FDI abroad in the US (outflow) are used to construct FDI intensity, defined as a ratio of total FDI flow (as a sum of both inflow and outflow) to manufacturing shipments. Since neither inflow nor outflow information is

[45] Annual growth rate of capacity utilization for aggregated industries, ΔCU_{At}, is calculated as a weighted sum of individual growths: $\Delta CU_{At} = (RVA_{it-1}\Delta CU_{it} + RVA_{jt-1}\Delta CU_{jt})/(RVA_{it-1} + RVA_{jt-1})$ for $i, j \in A$, where RVA_{it-1} and RVA_{jt-1} are real value added in year (t-1) for three-digit NAICS industry i and j, respectively. Real value added is calculated from real GDP index and nominal GDP (in millions of Canadian dollars). Benchmarked to 2002, real value added for industry i in year t, RVA_{it}, is calculated as: $RVA_{it} = NVA_{it} \times RVAI_{it}/100$, where NVA_{it} is the nominal GDP and $RVAI_{it}$ is the real GDP index with 2002=100.

[46] http://www.ic.gc.ca/sc_mrkti/tdst/tdo/tdo.php?lang=30&productType=NAICS

available for the leather products industry [316] due to confidentiality reasons, the dataset then uses the apparel industry's [315] FDI intensity as a proxy for the combined industries [315, 316]. Moreover, due to its small magnitude relative to the rest intensity measures, R&D intensity is scaled by a factor of 10. R&D expenditure information is unavailable in either the apparel or the leather industries due to confidentiality reasons.

Since the intensities dataset does not have complete time series over the full sample an average is taken over the available periods. As discussed in Chapter 2, averaging also has the advantage of smoothing out any fluctuation in these measures. Arguably, this broader description between the two countries is what the contribution these characteristics will make to the TFP transfer depends upon, rather than year-to-year fluctuations in these measures.

Table 5.1 lists the average annual growth of capacity utilization by manufacturing industries. A notable feature of the full sample averages is that for the majority of industries and the sector overall the growth rates are negative. In part, this is due to the recent recessions: for 2000-2010 (see Tables A3.2 and A3.3 for a comparison), all capacity utilization growth rates are negative. This supports the pro-cyclical role capacity utilization plays in the analysis.

Table 5.1 Canadian Capacity Utilization Growths by Industry (Percent)

NACIS Code	Industry Description	Average Annual Growth (percent) 1987-2010	1987-2000	2000-2010
311, 312	Food, beverage and tobacco products	0.060	0.350	-0.032
313, 314	Textiles mills and textile product mills	-1.013	-0.447	-0.175
315, 316	Apparel, leather and allied products	-0.903	-0.220	-0.179
321	Wood products	-0.679	-0.065	-0.148
322, 323	Paper, printing and related support activities	-0.351	-0.055	-0.073
324	Petroleum and coal products	-0.123	0.559	-0.101
325	Chemical products	-0.707	-0.776	-0.062
326	Plastics and rubber products	-0.918	-0.480	-0.149
327	Non-metallic minerals	-0.544	-0.454	-0.066
331	Primary metal	-0.724	-0.153	-0.147
332	Fabricated metal	-0.302	0.479	-0.132
333	Machinery	0.111	1.289	-0.142
334	Computers and electronic products	0.252	1.290	-0.110
335	Electrical equipment, appliances and components	-0.289	1.177	-0.219
336	Transportation equipment	0.094	0.929	-0.099
337, 339	Furniture and miscellaneous	-0.211	0.294	-0.087
31-33	Manufacturing	-0.303	0.292	-0.108

Source: Statistics Canada, author's calculations based on CASIM Table 028-0002 for 1987-2010 and Table 383-0022 for 1986-2008. See text for details.

Table 5.2 summarizes the industry characteristics considered in this study. It is notable that the R&D intensity post scaling in the computer and electronic industry exceeds 100 percent; this is likely due to substantially large amount of R&D activities in this industry relative to the other manufacturing industries. Overall, pairwise correlation of industry characteristics is positive in all cases. R&D intensity is quite highly correlated with the intensities of exports (41.1 percent), imports (51.6 percent) and with FDI (61.4 percent). Import intensity is also quite highly correlated with the intensities of export (48.0 percent) and FDI (36.6 percent). Moreover, industrial TFP growth in Canadian manufacturing is highly associated with export and R&D intensities (62.4 percent and 45.5 percent, respectively) and to a lesser degree with the intensities of FDI (17.9 percent) and import (13.8 percent).[47]

5.4 Empirical Analysis

5.4.1 Panel Analysis: Export, Import, FDI and R&D Intensities

To estimate equation (5.1), I allow for industry-specific fixed effects and fixed time effects; that is, the model includes a dummy variable for each year and for each industry. In addition, feasible GLS estimation is employed to allow for heteroskedasticity across panels.[48]

The analysis excludes the computer and electronic industry from the estimation. Total factor productivity growth (TFP) in this industry in the US is exceptionally high (19.1 percent on average) relative to other US manufacturing industries and relative to its Canadian counterpart. Consequently, it is anticipated that this industry would be an outlier in the panel analysis, possibly significantly influencing the results, and so the industry is dropped.[49]

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[47] An alternative modelling strategy is to include all intensities, as well as their interactions, in the regression. Doing so, however, results in loss in degrees of freedom.

[48] Standard tests for whether the variances are equivalent across panels are easily rejected. See Table A5.1 for details.

[49] Table A5.2 reports the regression results using the full sample.

Table 5.2 Intensity Measures and Correlations

NACIS Code	Description	Average Intensity: Export (1992-2010)	Import (1992-2010)	FDI (1999-2010)	R&D † (1994-2010)
311, 312	Food, beverage, and tobacco	0.149	0.355	0.148	0.017
313, 314	Textiles and mills	0.288	0.110	0.065	0.079
315, 316	Apparel and leather products	0.272	0.468	0.011	x
321	Wood products	0.459	0.124	0.150	0.031
322, 323	Paper and printing products	0.391	0.064	0.273	0.063
324	Petroleum and coal products	0.256	0.135	0.167	0.038
325	Chemical products	0.392	0.069	0.314	0.247
326	Plastics and rubber products	0.420	0.517	0.202	0.056
327	Non-metallic mineral products	0.221	0.344	0.437	0.045
331	Primary metal	0.449	0.237	0.164	0.051
332	Fabricated metal	0.216	0.224	0.145	0.053
333	Machinery	0.545	0.330	0.129	0.168
334	Computer and electronic products	0.566	0.844	0.490	1.073
335	Electrical equipment	0.448	0.841	0.405	0.177
336	Transportation equipment	0.719	0.738	0.174	0.123
337, 339	Furniture and miscellaneous	0.405	0.559	0.113	0.089
31 - 33	Manufacturing	0.426	0.353	0.218	0.143
Pairwise Correlation	Export	1.000	0.480	0.198	0.411
	Import		1.000	0.366	0.516
	FDI			1.000	0.614
	R&D				1.000
Correlation with TFP growth		0.624	0.138	0.137	0.455

† R&D intensities are scaled by 10.

The estimated models are presented in Table 5.3. For space considerations, constant, time- and industry-specific fixed effects are not reported nor are the coefficients for the industry-specific lagged dependent variables. The time fixed effects are jointly significant with a number of statistically significant individual years. In contrast, the industry fixed effects are jointly insignificant. Finally, the lagged dependent variables are statistically insignificant more often than not and range in values from roughly -0.3 to 0.4. A test that the coefficients on the lagged dependent variables across industries are jointly equal to zero cannot be rejected. Since dropping out the industry fixed effects and lagged dependent variables has little impact, these variables are kept in the regression estimation.

Table 5.3 summarizes the panel estimation of equation (5.1). Column (1) focuses on the effects of US productivity growth alone; it serves as a benchmark for the other models reported in columns (2) - (5), which consider the industry intensities in isolation.

Comparing and contrasting models (1)-(5) leads to two general conclusions. First, capacity utilization growth is positive and statistically significant at standard levels. A one percent increase in the growth of capacity utilization raises TFP growth in Canadian manufacturing by 0.5 percent on average. This suggests the importance to include capacity utilization to control for pro-cyclicality in the TFP estimates.

Second, all models reveals a positive and significant effect from contemporaneous US productivity growth but no effect from lagged US productivity growth. Specifically, the *average* effects of US productivity growth on Canadian productivity growth, conditional on the industrial *average* of a particular intensity measure, are estimated in year t and t-1 as:

$$\left.\frac{d\Delta x_{it}}{d\Delta x_{it}^{*}}\right|_{w_i=\overline{w}_i} = \eta_1 + \delta_1 \overline{w}_i \text{, and } \left.\frac{d\Delta x_{it}}{d\Delta x_{it-1}^{*}}\right|_{w_i=\overline{w}_i} = \eta_2 + \delta_2 \overline{w}_i$$

These effects are reported in the bottom of Table 5.3.

Table 5.3 Canadian Industries Productivity Growth

$$\Delta x_{it} = \beta_0 + \eta_1 \Delta x_t^* + \delta_1 w_i \Delta x_t^* + \eta_2 \Delta x_{t-1}^* + \delta_2 w_i \Delta x_{t-1}^* + \beta_3 \Delta CU_{it} + \beta_{i4} \Delta x_{it-1} + \varepsilon_{it}$$

	None (1)	Export Intensity (2)	Import Intensity (3)	FDI Intensity (4)	R&D Intensity (5)
Δx_{it}^*	0.097	-0.004	0.168	0.045	0.108
	(0.031)	(0.079)	(0.051)	(0.053)	(0.050)
Δx_{it-1}^*	0.006	-0.187	-0.123	-0.079	0.079
	(0.034)	(0.085)	(0.055)	(0.061)	(0.052)
ΔCU_{it}	0.469	0.466	0.481	0.477	0.464
	(0.053)	(0.053)	(0.053)	(0.052)	(0.053)
$w_i \Delta x_{it}^*$		0.272			
		(0.203)			
$w_i \Delta x_{it-1}^*$		0.548			
		(0.227)			
$w_i \Delta x_{it}^*$			-0.252		
			(0.146)		
$w_i \Delta x_{it-1}^*$			0.449		
			(0.157)		
$w_i \Delta x_{it}^*$				0.326	
				(0.248)	
$w_i \Delta x_{it-1}^*$				0.465	
				(0.284)	
$w_i \Delta x_{it}^*$					-0.147
					(0.499)
$w_i \Delta x_{it-1}^*$					-0.888
					(0.522)
H_0: $\eta_1 = \eta_2 = 0$					
$\chi^2(2)$	9.966	4.907	20.277	2.912	5.995
p-value	0.007	0.086	0.000	0.233	0.050
H_0: $\delta_1 = \delta_2 = 0$					
$\chi^2(2)$		6.942	13.777	3.875	2.935
p-value		0.031	0.001	0.144	0.230
H_0: $\delta_1 + \delta_2 = 0$		0.819	0.197	0.791	-1.035
$\chi^2(1)$		6.472	0.698	3.858	1.582
p-value		0.011	0.404	0.050	0.208
H_0: $\eta_1 + \delta_1 \overline{w}_i = 0$		0.098	0.082	0.108	0.095
$\chi^2(1)$		3.163	2.581	3.491	2.942
p-value		0.002	0.010	0.000	0.003
H_0: $\eta_2 + \delta_2 \overline{w}_i = 0$		0.018	0.030	0.011	0.000
$\chi^2(1)$		0.526	0.869	0.326	0.008
p-value		0.599	0.385	0.744	0.993

(Table 5.3 continued on next page…)

(… Table 5.3 continued…)

$$\Delta x_{it} = \beta_0 + \eta_1 \Delta x_t^* + \delta_1 w_i \Delta x_t^* + \eta_2 \Delta x_{t-1}^* + \delta_2 w_i \Delta x_{t-1}^* + \beta_3 \Delta CU_{it} + \beta_{i4} \Delta x_{it-1} + \varepsilon_{it}$$

	None (1)	Export Intensity (2)	Import Intensity (3)	FDI Intensity (4)	R&D Intensity (5)
H_0: Coefficients of year-specific fixed effect jointly equal zero					
$\chi^2(21)$	130.903	130.204	134.764	135.274	127.227
p-value	0.000	0.000	0.000	0.000	0.000
H_0: Coefficients of industry-specific fixed effect jointly equal zero					
$\chi^2(14)$	19.614	19.942	20.130	19.508	18.925
p-value	0.143	0.132	0.126	0.146	0.125
H_0: Coefficients of industry-specific lagged dependent variable jointly equal zero					
$\chi^2(15)$	14.020	12.787	12.943	14.597	10.150
p-value	0.524	0.619	0.607	0.481	0.751
Bayesian IC	-818.097	-812.379	-818.694	-809.611	-763.269
No. of Obs.	330	330	330	330	308
No. of Industries	15	15	15	15	14

Note: Sample period is 1987-2010, computer and electronics [334] excluded. Each regression includes a constant, industry fixed effects, time effects, and an industry-specific lagged dependent variable; coefficients not reported. Each model is estimated using iterated GLS allowing for industry specific variances. For x_{it} and x_{it}^*, Canadian and US total factor productivity by industry is used. For model (5) the joint test for industry-specific fixed effect and lagged dependent variable has 13 and 14 degrees of freedom, respectively. Numbers in parentheses are standard errors. Numbers in shade denotes 10% significance level.

The contemporaneous US impact ranges from 0.08 and 0.11; a one percent increase in current US productivity gives rise to an immediate increase, varying from 0.08 to 0.11 percent, in Canadian productivity on average. This positive contemporaneous effect is further confirmed by individual industry investigations; as shown in the left panel of Table 5.4, the short-run multiplier effects are positive, more often than not, and significant. Notably, this result differs from the VAR results (in Chapter 4) wherein Canadian responses by industry to US shocks are not uniform.

As far as the impact of these intensities is concerned, a clean interpretation of how the different industry characteristics contribute to the effect of US productivity growth is difficult. For export intensity in column (2), the coefficient on the current intensity interaction term, δ_1, is positive yet insignificant while the coefficient on the lagged term, δ_2, is positive and significant. The joint test that both δ coefficients equal zero is easily rejected at 5 percent significance level. Moreover, the sum effect of the two interaction terms is positive and significant. Consequently, the greater is export intensity, the greater is the short-run effect on Canadian productivity from an increase in US productivity.

For import intensity in column (3), the δ coefficients are both significant but of opposite signs, with δ_2 greater than δ_1 in absolute value. The joint test that both δ coefficients equal zero is rejected at standard significance levels. However, the sum effect of the two interaction terms is positive and statistically insignificant. In other words, import intensity influences the technology transmission from the US, negatively on the current US productivity innovations whereas positively on the previous ones. These two impacts, however, offset each other, resulting in zero total effect in the short run. Evidently, the role of import intensities in technology diffusion is not easily modelled.

For FDI intensity in column (4), the δ coefficients are both positive but only δ_2 is statistically significant. The sum effect of the two interaction terms, however, is positive and significant at the 5 percent significance level. These results indicate a positive role for FDI intensity in technology diffusion. The null hypothesis that the δ coefficients jointly equal zero cannot be rejected at standard levels. This contradicts with the earlier results and casts doubt on FDI's role in technology diffusion in the short run.

Lastly, for R&D intensity in column (5), the δ coefficients are both negative and δ_2 is statistically significant. Initially, the hypothesis is that R&D should raise absorptive capacity in a competitive market and thereby facilitate technology diffusion. The present result, however, suggests that a US productivity shock is less likely to pass through the greater is domestic R&D. This, in turn, indicates Canadian industries with high R&D are more resilient to US productivity innovations. Moreover, the δ coefficients are jointly insignificant and the sum effect is negative and insignificant, both of which suggest an insignificant role of R&D. Clearly the dynamics in the last two models are complicated in the short-run.[50] With no unambiguous conclusions, the next step is to see what we can learn from the longer-run effects.

It is worth bearing in mind that the current analysis does not attempt to discriminate amongst different industry characteristics whereby all industry intensities are explanatory variables as well as their interactions with US productivity growth and each other. Such models are impractical here with the limited data available. Instead, the analysis limits its attention to the Canadian TFP changes arising from those in its US counterparts, examining industry-specific features on at a time. The downside of this approach is that the effects of US productivity shocks are specific to each industry-specific model. With no means to discriminate between the models I am left with many potentially different predictions of these effects, all of which are valid. To focus the discussion, the remainder of discussion concerning US long-run multiplier effect considers the prediction of export intensity model, model (2), only.

5.4.2 Long-Run Multiplier Effect

Two long-run multiplier effects on Canadian TFP growth are calculated at the steady state: the first is the long-run multiplier effect of a permanent improvement in US productivity growth, and the second is the long-run multiplier effect of permanent shifts

[50] As discussed in Chapter 2, it is possible that these industry intensities play a direct role in increasing TFP in Canada, which would be picked up by the fixed effects; in fact, as there is little evidence in support of the fixed effects this does not appear to be the case. In any event, the focus of the current analysis is specifically on whether intensities contribute to the interdependence across the border and not the industry growth rate.

in industry characteristics. The results are reported in the right panel of Tables 5.4 and Table 5.5, respectively.

The right panel of Table 5.4 reports the values for US long-run multiplier effects by industry. The test statistics for the null hypotheses that these effects are zero are also presented. The test statistics are based upon a delta approximation. The following discussion, as addressed earlier, focuses exclusively on Canadian dependence on its US counterpart by individual industry though export intensity – the first set of results in Table 5.4. In general, the long-run effects of an increase in US productivity growth are positive, though not uniform in magnitude across industries. Note that the productivity growth rates used in the estimation (log first differences) have not been scaled by 100. The reported numbers can be then interpreted as follows.

In the first instance, let us look at the transportation equipment industry – the industry with the highest long-run multiplier effect of 0.4. Initially, Canadian and US productivity growth rates are 1.9 percent and -0.4 percent, respectively. A one percent permanent increase in US productivity growth to 0.6 percent would raise Canadian productivity growth at the steady state by 0.4 percent to 2.3 percent. Take machinery as another example; the long-run multiplier of this industry is 0.3. Both Canadian and US productivity growth rates are originally 1 percent. A one percent permanent increase in US productivity growth to 2 percent would raise Canadian productivity growth, also in steady state, by 0.3 percent; that is, to 1.3 percent permanently.

As far as the long-run multiplier effects of industry intensities are concerned, one way to interpret their impact relates back to US long-run multiplier effects, which can be expressed as

$$\frac{d\mathbf{\Delta}x_i}{d\mathbf{\Delta}x_i^*} = \frac{1}{1-\beta_{i4}}\left[\eta_1 + \eta_2 + (\delta_1 + \delta_2)w_i\right]$$

Table 5.4 Multiplier Effects of US Productivity Growth

	Contemporaneous Effect			Long-Run Effect			
Model (2): Export Intensity	Multiplier	$\chi^2(1)$	*p*-value	Multiplier	$\chi^2(1)$	*p*-value	$\overline{\Delta x_i^*}$
Food, beverage, and tobacco	0.037	0.499	0.480	-0.066	0.615	0.433	-0.002
Textiles	0.075	4.885	0.027	0.043	0.686	0.408	0.029
Apparel and leather	0.070	3.936	0.047	0.022	0.300	0.584	0.033
Wood	0.121	10.564	0.001	0.254	5.382	0.020	0.005
Paper and printing	0.103	10.513	0.001	0.126	5.625	0.018	0.005
Petroleum and coal	0.066	3.154	0.076	0.016	0.094	0.759	0.040
Chemical	0.103	10.531	0.001	0.129	5.689	0.017	-0.004
Plastics and rubber	0.111	10.904	0.001	0.169	6.585	0.010	0.014
Non-metallic minerals	0.057	1.875	0.171	-0.010	0.020	0.887	0.001
Primary metal	0.118	10.727	0.001	0.148	7.777	0.005	0.008
Fabricated metal	0.055	1.728	0.189	-0.011	0.040	0.841	0.000
Machinery	0.145	8.600	0.003	0.261	10.122	0.002	0.010
Electrical equipment	0.118	10.727	0.001	0.165	7.290	0.007	0.005
Transportation equipment	0.192	5.750	0.017	0.398	7.939	0.005	-0.004
Furniture and misc.	0.106	10.779	0.001	0.135	5.832	0.016	0.032

	Contemporaneous Effect			Long-Run Effect			
Model (3): Import Intensity	Multiplier	$\chi^2(1)$	*p*-value	Multiplier	$\chi^2(1)$	*p*-value	$\overline{\Delta x_i^*}$
Food, beverage, and tobacco	0.078	5.863	0.016	0.102	5.008	0.025	-0.002
Textiles	0.140	12.530	0.000	0.067	1.076	0.300	0.029
Apparel and leather	0.050	1.494	0.222	0.098	3.985	0.046	0.033
Wood	0.137	12.707	0.000	0.095	1.109	0.292	0.005
Paper and printing	0.152	11.796	0.001	0.058	0.642	0.423	0.005
Petroleum and coal	0.134	12.823	0.000	0.062	1.317	0.251	0.040
Chemical	0.150	11.889	0.001	0.060	0.695	0.405	-0.004
Plastics and rubber	0.037	0.661	0.416	0.162	3.458	0.063	0.014
Non-metallic minerals	0.081	6.483	0.011	0.112	4.716	0.030	0.001
Primary metal	0.108	11.977	0.001	0.075	3.046	0.081	0.008
Fabricated metal	0.111	12.334	0.000	0.072	3.007	0.083	0.000
Machinery	0.084	7.285	0.007	0.115	4.528	0.033	0.010
Electrical equipment	-0.044	0.259	0.611	0.218	2.049	0.152	0.005
Transportation equipment	-0.018	0.062	0.803	0.188	2.429	0.119	-0.004
Furniture and misc.	0.027	0.283	0.595	0.142	3.099	0.078	0.032

(*Table 5.4 continued on next page…*)

(… *Table 5.4 continued*)

	Contemporaneous Effect			Long-Run Effect			
Model (4): FDI Intensity	Multiplier	$\chi^2(1)$	*p*-value	Multiplier	$\chi^2(1)$	*p*-value	$\overline{\Delta x_i^*}$
Food, beverage, and tobacco	0.093	8.837	0.003	0.073	2.780	0.095	-0.002
Textiles	0.066	2.573	0.109	0.017	0.065	0.798	0.029
Apparel and leather	0.048	0.895	0.344	-0.018	0.091	0.763	0.033
Wood	0.094	8.994	0.003	0.114	2.247	0.134	0.005
Paper and printing	0.134	11.784	0.001	0.175	7.553	0.006	0.005
Petroleum and coal	0.099	10.513	0.001	0.087	3.463	0.063	0.040
Chemical	0.147	10.241	0.001	0.209	7.401	0.007	-0.004
Plastics and rubber	0.111	12.544	0.000	0.143	5.165	0.023	0.014
Non-metallic minerals	0.187	6.825	0.009	0.302	7.709	0.006	0.001
Primary metal	0.098	10.267	0.001	0.080	3.429	0.064	0.008
Fabricated metal	0.092	8.502	0.004	0.064	2.427	0.119	0.000
Machinery	0.087	7.082	0.008	0.072	1.603	0.206	0.010
Electrical equipment	0.177	7.501	0.006	0.267	6.212	0.013	0.005
Transportation equipment	0.101	11.000	0.001	0.110	3.599	0.058	-0.004
Furniture and misc.	0.082	5.677	0.017	0.053	0.923	0.337	0.032

	Contemporaneous Effect			Long-Run Effect			
Model (5): R&D Intensity	Multiplier	$\chi^2(1)$	*p*-value	Multiplier	$\chi^2(1)$	*p*-value	$\overline{\Delta x_i^*}$
Food, beverage, and tobacco	0.106	5.921	0.015	0.145	6.547	0.011	-0.002
Textiles	0.097	9.215	0.002	0.098	3.990	0.046	0.029
Wood	0.104	7.059	0.008	0.203	4.459	0.035	0.005
Paper and printing	0.099	9.285	0.002	0.117	5.051	0.025	0.005
Petroleum and coal	0.103	7.653	0.006	0.131	5.245	0.022	0.040
Chemical	0.072	0.621	0.431	-0.073	0.193	0.661	-0.004
Plastics and rubber	0.100	8.980	0.003	0.145	4.950	0.026	0.014
Non-metallic minerals	0.102	8.227	0.004	0.138	6.191	0.013	0.001
Primary metal	0.101	8.670	0.003	0.112	5.484	0.019	0.008
Fabricated metal	0.100	8.802	0.003	0.104	5.938	0.015	0.000
Machinery	0.083	2.237	0.135	0.014	0.019	0.890	0.010
Electrical equipment	0.082	1.902	0.168	0.003	0.001	0.971	0.005
Transportation equipment	0.090	5.215	0.022	0.065	0.782	0.377	-0.004
Furniture and misc.	0.095	8.607	0.003	0.090	2.872	0.090	0.032

Note: Estimates are based upon the models in column (2)-(5) of Table 5.3, with computer and electronics [334] excluded from the sample. Multiplier effect is calculated as detailed in text. $\chi^2(1)$ denotes the test statistics for the null hypothesis that the multiplier coefficient is zero; inference is based upon a delta approximation.

Let us denote this effect as $\mu_i(w_i)$. These long-run effects are industry dependent governed by industry-specific growth path (β_{i4}) and intensity (w_i). One can then ask how the industry characteristics influence the effect of US productivity growth on Canadian productivity growth, or equivalently

$$\frac{d\mu_i(w_i)}{dw_i} = \frac{1}{1-\beta_{i4}}(\delta_1 + \delta_2)$$

For the most part, the β_{i4} parameters are statistically insignificant and thereby do not play an important role. The direction and magnitude of long-run intensity effect on technology diffusion is therefore determined by the sum of δ parameters, an average of which is illustrated in Table 5.3. Combined with these results, the conclusion would appear to be:

(1) a positive effect of export/FDI intensities on long-run technology diffusion; and
(2) a zero effect of import/R&D intensities on long-run technology diffusion.

Table 5.5 report these long-run multipliers of industry characteristics. Indeed, export and FDI intensities appear to facilitate long-run technology diffusion in most Canadian industries. In contrast, import and R&D intensities do not have any bearings – a result consistent with Table 5.2.

For brevity, the discussion focuses on the multiplier effects of export and FDI intensities, where long-run effects are significant. Most industries see positive multiplier effects. The petroleum and coal industries, for example, have the highest multiplier effect of 0.28 in both cases. To put it in perspective, a one percent permanent increase in either export intensity to 26.6 percent (from 25.6 percent) or FDI intensity to 17.7 percent (from 16.7 percent) raises Canadian productivity in this industry by 0.03 percent permanently to 0.93 percent.

Table 5.5 Long-Run Multiplier Effects of Canadian Industry Intensities

	Change in Export intensity				Change in Import intensity			
Industry Description	Multiplier	$\chi^2(1)$	*p*-value	w_i	Multiplier	$\chi^2(1)$	*p*-value	w_i
Food, beverage, and tobacco	-0.001	4.781	0.029	0.149	0.000	0.690	0.406	0.355
Textiles	0.023	5.672	0.017	0.288	0.006	0.677	0.411	0.110
Apparel and leather products	0.019	5.965	0.015	0.272	0.005	0.685	0.408	0.468
Wood products	0.005	4.235	0.040	0.459	0.001	0.654	0.419	0.124
Paper and printing products	0.004	5.678	0.017	0.391	0.001	0.677	0.411	0.064
Petroleum and coal products	0.028	5.491	0.019	0.256	0.007	0.684	0.408	0.135
Chemical products	-0.004	5.603	0.018	0.392	-0.001	0.662	0.416	0.069
Plastics and rubber products	0.013	5.678	0.017	0.420	0.003	0.677	0.411	0.517
Non-metallic mineral products	0.001	5.655	0.017	0.221	0.000	0.692	0.405	0.344
Primary metal	0.005	5.802	0.016	0.449	0.001	0.687	0.407	0.237
Fabricated metal	0.000	5.828	0.016	0.216	0.000	0.682	0.409	0.225
Machinery	0.008	6.329	0.012	0.546	0.002	0.690	0.406	0.330
Electrical equipment	0.004	5.438	0.020	0.449	0.001	0.671	0.413	0.841
Transportation equipment	-0.003	5.708	0.017	0.719	-0.001	0.688	0.407	0.738
Furniture and miscellaneous	0.025	5.551	0.019	0.405	0.006	0.665	0.415	0.559

	Change in FDI intensity				Change in R&D intensity			
Industry Description	Multiplier	$\chi^2(1)$	*p*-value	w_i	Multiplier	$\chi^2(1)$	*p*-value	w_i
Food, beverage, and tobacco	-0.001	3.611	0.057	0.148	0.002	1.615	0.204	0.017
Textiles	0.022	3.504	0.061	0.065	-0.028	1.521	0.217	0.079
Apparel and leather products	0.018	3.720	0.054	0.011	x	x	x	x
Wood products	0.005	2.934	0.087	0.150	-0.006	1.446	0.229	0.031
Paper and printing products	0.004	3.637	0.057	0.273	-0.005	1.536	0.215	0.063
Petroleum and coal products	0.028	3.459	0.063	0.167	-0.036	1.499	0.221	0.038
Chemical products	-0.003	3.630	0.057	0.314	0.005	1.348	0.246	0.247
Plastics and rubber products	0.013	3.401	0.065	0.202	-0.017	1.492	0.222	0.056
Non-metallic mineral products	0.001	3.984	0.046	0.437	-0.001	1.565	0.211	0.045
Primary metal	0.005	3.613	0.057	0.164	-0.007	1.532	0.216	0.051
Fabricated metal	0.000	3.667	0.056	0.145	0.000	1.551	0.213	0.053
Machinery	0.008	3.644	0.056	0.129	-0.011	1.509	0.219	0.168
Electrical equipment	0.004	3.420	0.064	0.405	-0.005	1.530	0.216	0.177
Transportation equipment	-0.003	3.308	0.069	0.174	0.004	1.455	0.228	0.123
Furniture and miscellaneous	0.024	3.618	0.057	0.113	-0.031	1.530	0.216	0.089

Note: Estimates are based upon the model in column (2)-(5) of Table 5.3, with computer and electronics excluded from the sample. Multipliers are calculated as detailed in text. $\chi^2(1)$ denotes the test statistics for the null hypothesis that the multiplier coefficient is zero; inference is based upon a delta approximation. Number in shade denotes 10% significance level.

The negative multipliers appear in three industries: (1) food, beverage, and tobacco; (2) chemical products; and (3) transportation equipment. In each of these industries, a permanent improvement in intensity is translated into a permanent deterioration in Canadian productivity. Note that for these industries the average TFP growth rates in 1987-2010 are positive in Canada in contrast to negative average growth rates in their counterparts (Table 4.1). In other words, the industry intensity multipliers might simply reflect this average relationship.

Two puzzles, however, are left unsolved. First, no model specified in Table 5.3 demonstrates a significantly negative long-run impact on the petroleum and coal industry from US productivity innovations, as predicted by the VAR analysis in the previous chapter. Second, import and R&D intensities do not have any bearing on technology diffusion in the long run.

5.5 Conclusions

It is well known that Canadian industries lag US industries in productivity, both in levels as well as in growth rates. The current analysis examines the empirical relationships between total factor productivity (TFP) for US and Canadian industries, with the objective of uncovering the extent of dependence of Canadian TFPs on US counterparts. This analysis is designed to see the extent to which Canadian productivity depends upon its US counterpart on an industry basis as well as to see whether certain industry characteristics facilitate this dependence.

With no evidence of convergence in TFP between Canadian and US manufacturing industries, the paper takes a purely empirical perspective and look at TFP relationships between the two countries on an industry basis. It asks to what extent US productivity shocks feed through into higher Canadian TFPs. Because industry characteristics, such as international trade, foreign direct investment (FDI), and research and development (R&D), may facilitate the transmission of innovation from the US to Canada, the paper considers a panel model allowing for industry characteristics to determine the extent of technology diffusion. The paper finds that changes in US productivity growth have an immediate positive impact on Canadian productivity growth on average. All industry characteristics appear to be an important conduit for productivity in the short run.

Surprisingly, an increase in R&D intensity reduces foreign innovation transmission, indicating high resilience to US innovation shocks in Canadian industries with a high level of R&D expenditures. In contrast, the long-run impact of US productivity growth is not uniform across industries.

The study points out a potential direction for future study. Given the large variation in productivity growth patterns across manufacturing industries, it is worthwhile to consider the growth context in a firm-level analysis. Industry turnover is indicative of an industry's competitiveness (Baldwin and Gu, 2006), which is also highly correlated with productivity. Recent evidence on Canadian manufacturing shows high correlation between productivity and firms' dynamics; entrants are less productive than continuing firms, yet more productive than exits due to lower capital intensity and smaller in size (Tang and Liu, 2012). Foster, Haltiwanger and Syverson (2008) argue that successful firm entrants replace less profitable firms yet not necessarily less productive firms. By investigating firms' growth process by industry it may shed additional light on the cross-border dynamics.

Appendix Tables

Table A5.1 Log-Likelihood Ratio Test for Cross-Industry Heteroskedasticity

Model Specification	Industry Characteristics	Explanatory Variables			
		$\Delta x_{\mathrm{it}}^{*}$		$\Delta x_{\mathrm{t}}^{*}$	
		LR ratio	*p*-value	LR ratio	*p*-value
(1)	None	99.024	0.000	106.191	0.000
(2)	Export Intensity	97.682	0.000	106.206	0.000
(3)	Import Intensity	99.478	0.000	102.489	0.000
(4)	FDI Intensity	98.828	0.000	103.667	0.000
(5)	R&D Intensity	99.433	0.000	148.863	0.000

Note: Growth measures in US total factor productivity considered include Δx_{it}^{*} by industry and Δx_{t}^{*} by sector. Under the null hypothesis, there is no significant difference in estimates of restricted (homoskedasticity) and unrestricted (heteroskedasticity) models. Rejection of the null favours the unrestricted model.

Table A5.2 Canadian Industries Productivity Growth

$\Delta x_{it} = \beta_0 + \eta_1 \Delta x_t^* + \delta_1 w_i \Delta x_t^* + \eta_2 \Delta x_{t-1}^* + \delta_2 w_i \Delta x_{t-1}^* + \beta_3 \Delta CU_{it} + \beta_{i4} \Delta x_{it-1} + \varepsilon_{it}$

	None (1)	Export Intensity (2)	Import Intensity (3)	FDI Intensity (4)	R&D Intensity (5)
Δx_{it}^*	0.097	-0.004	0.168	0.045	0.108
	(0.031)	(0.079)	(0.051)	(0.053)	(0.050)
Δx_{it-1}^*	0.006	-0.187	-0.123	-0.079	0.079
	(0.034)	(0.085)	(0.055)	(0.061)	(0.052)
ΔCU_{it}	0.469	0.466	0.481	0.477	0.464
	(0.053)	(0.053)	(0.053)	(0.052)	(0.053)
$w_i \Delta x_{it}^*$		0.272			
		(0.203)			
$w_i \Delta x_{it-1}^*$		0.548			
		(0.227)			
$w_i \Delta x_{it}^*$			-0.252		
			(0.146)		
$w_i \Delta x_{it-1}^*$			0.449		
			(0.157)		
$w_i \Delta x_{it}^*$				0.326	
				(0.248)	
$w_i \Delta x_{it-1}^*$				0.465	
				(0.284)	
$w_i \Delta x_{it}^*$					-0.147
					(0.499)
$w_i \Delta x_{it-1}^*$					-0.888
					(0.522)
H_0: $\eta_1 = \eta_2 = 0$					
$\chi^2(2)$	9.966	4.907	20.277	2.912	5.995
p-value	0.007	0.086	0.000	0.233	0.050
H_0: $\delta_1 = \delta_2 = 0$					
$\chi^2(2)$		6.942	13.777	3.875	2.935
p-value		0.031	0.001	0.144	0.230
H_0: $\delta_1 + \delta_2 = 0$		0.819	0.197	0.791	-1.035
$\chi^2(1)$		6.472	0.698	3.858	1.582
p-value		0.011	0.404	0.050	0.208
H_0: $\eta_1 + \delta_1 \overline{w}_i = 0$		0.098	0.082	0.108	0.095
$\chi^2(1)$		3.163	2.581	3.491	2.942
p-value		0.002	0.010	0.000	0.003
H_0: $\eta_2 + \delta_2 \overline{w}_i = 0$		0.018	0.030	0.011	0.000
$\chi^2(1)$		0.526	0.869	0.326	0.008
p-value		0.599	0.385	0.744	0.993

(Table A5.2 continued on next page…)

(… Table A5.2 continued…)

$\Delta x_{it} = \beta_0 + \eta_1 \Delta x_t^* + \delta_1 w_i \Delta x_t^* + \eta_2 \Delta x_{t-1}^* + \delta_2 w_i \Delta x_{t-1}^* + \beta_3 \Delta CU_{it} + \beta_{i4} \Delta x_{it-1} + \varepsilon_{it}$	None (1)	Export Intensity (2)	Import Intensity (3)	FDI Intensity (4)	R&D Intensity (5)
H_0: Coefficients of year-specific fixed effect jointly equal zero					
$\chi^2(21)$	130.903	130.204	134.764	135.274	127.227
p-value	0.000	0.000	0.000	0.000	0.000
H_0: Coefficients of industry-specific fixed effect jointly equal zero					
$\chi^2(14)$	19.614	19.942	20.130	19.508	18.925
p-value	0.143	0.132	0.126	0.146	0.125
H_0: Coefficients of industry-specific lagged dependent variable jointly equal zero					
$\chi^2(15)$	14.020	12.787	12.943	14.597	10.150
p-value	0.524	0.619	0.607	0.481	0.751
Bayesian IC	-818.097	-812.379	-818.694	-809.611	-763.269
No. of Obs.	330	330	330	330	308
No. of Industries	15	15	15	15	14

Note: Sample period is 1987-2010, computer and electronics [334] excluded. Each regression includes a constant, industry fixed effects, time effects, and an industry-specific lagged dependent variable; coefficients not reported. Each model is estimated using iterated GLS allowing for industry specific variances. For x_{it} and x_{it}^*, Canadian and US total factor productivity by industry is used. For model (5) the joint test for industry-specific fixed effect and lagged dependent variable has 13 and 14 degrees of freedom, respectively. Numbers in parentheses are standard errors. Numbers in shade denotes 10% significance level.

Chapter 6 Conclusion

Canada and the US are highly integrated economies. In addition to extensive bilateral trade and investment, the countries share a common language. They have similar market structures and regulation, and labour is fairly mobile between the countries. All these features suggest that productivity at the sector and/or industry level should be similar across countries. However, significant and persistent gaps exist in productivity between Canadian and US industries.

The motivation of this dissertation is threefold. First, it seeks to find whether there is a long-run relationship in productivity between Canada and the US by manufacturing industry. Second, this dissertation thoroughly identifies whether US productivity innovations have an immediate and/or permanent impact, if any, on Canadian counterparts. Third, this dissertation seeks to quantify how industry characteristics may facilitate technology diffusion.

Chapter 2 examines the relationship between Canadian and US labour productivity in manufacturing and its component industry sectors. This study finds no evidence of convergence or other long run relationships for manufacturing as a whole or on an industry basis. The study does find, however, some relationship between industry labour productivity growth rates, though the extent of the interdependence between industries in Canada and the US is surprisingly small and varies significantly across industries. Finally, the study examines whether the industry intensities of exports, foreign direct investment and research and development expenditures have any bearing on the interdependence we do observe; there appears to be some role for export intensity to increase the interdependence between industries across borders.

National statistics offices in different countries, as well as individual researchers, make a range of different assumptions and use different approaches to estimating TFP growth. These methodological choices typically reflect a combination of data availability and the objectives of the study. For example, national statistics offices typically have access to more disaggregated data than outside researchers due to confidentiality considerations.

Other differences reflect different theoretical and practical considerations related to, for example, calculations of capital user cost, which can have implications for growth measures of capital input and thereby TFP growth. As a result, TFP growth estimates can vary for a given time period for a country. Chapter 3 uses "reasonably" comparable data for output, labour and capital in Canada and the US to investigate the sensitivity of TFP growth estimates (by industry and for the business sector in the two countries) to three alternative methodological assumptions. This chapter shows that TFP growth estimates for both countries, as well as the Canada-US TFP growth gap, are fairly robust to the alternative methodologies and assumptions considered.

Using the newly developed data set of comparable TFP measures from Chapter 3, Chapter 4 examines the TFP relationships between Canada and US in the manufacturing sector and its component industries, using standard time series methods on an industry-by-industry basis. The study finds little evidence of long-run convergence in productivity within manufacturing between the two countries. Industry-specific VAR models further suggest that at the industry level productivity technology diffusion from the US to Canadian counterparts is somewhat limited and non uniform across industries.

Building upon Chapter 4, Chapter 5 seeks to quantify the relationship between US and Canadian TFPs in manufacturing industries, again using the TFP growth estimates developed in Chapter 3. Dynamic panel estimation is employed to determine whether certain industry characteristics thought to influence the diffusion of technology do so in the Canada-US context. The study shows that the US productivity innovations are an important source of Canadian productivity growth, though primarily in the short run rather than the long run. Export, import and foreign direct investment (FDI) intensities are found to be important channels for technology diffusion from the US in the short run. Surprisingly, a higher research and development intensity reduces short-run technology diffusion on average. In the long run, export and FDI intensities contribute to technology diffusion.

Of course, this dissertation does not attempt to explore the underlying reasons for the existing gap in productivity between Canada and US manufacturing industries. Instead, it attempts to document the extent Canadian manufacturing industries depend upon its US counterparts. The results of this dissertation should be interpreted taking into account the shortcomings associated with the data and analysis as well as the simplifications in the theoretical model. Nevertheless, the non-converging productivity growth pattern and the non-uniform technology diffusion found in this dissertation should be of interest to industrial policy makers. Finally, these results serve as an inspiration to the academic researchers of micro study on firms' behaviour and growth pattern.

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