The Role of Public Infrastructure Investment: its Development and Contributions to Economic Growth

By

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Abstract:

Canada's response to the recent global economic crisis reflected that of many Western nations – one that centred on fiscal stimulus packages with large funds allocated towards infrastructure development. This paper uses modified-Wald tests in bivariate autoregressive models to examine whether factor inputs, specifically public fixed capital investment and other determinants of economic growth, are complements (or substitutes). National accounting data is used at the provincial, national, and international levels to test for complementary relationships. Test results could not produce any robust evidence of any one-way or dual causal relationships in the levels or growth rates among any of these subsets. However despite no evidence of these short-run relationships, the Johansen cointegration test identifies long-run relationships between Canada's public and private investments, employment, and labour productivity. Furthermore the impact of Canadian public investment growth on output growth demonstrates a dual causal relationship, running positively from investment to output, but negatively in the reverse causation. This study supports the notion of functional finance in the Canadian context, in that increases to public infrastructure growth contribute to increased output growth, but that increased output growth leads decreases in public investment growth. I conclude with an exploratory discussion involving the development of specific industries in a Kaldorian context, highlighting the shift of Canada's industry sectors from manufacturing to natural resources, which may indeed be a source of our declining productivity growth.

Introduction:

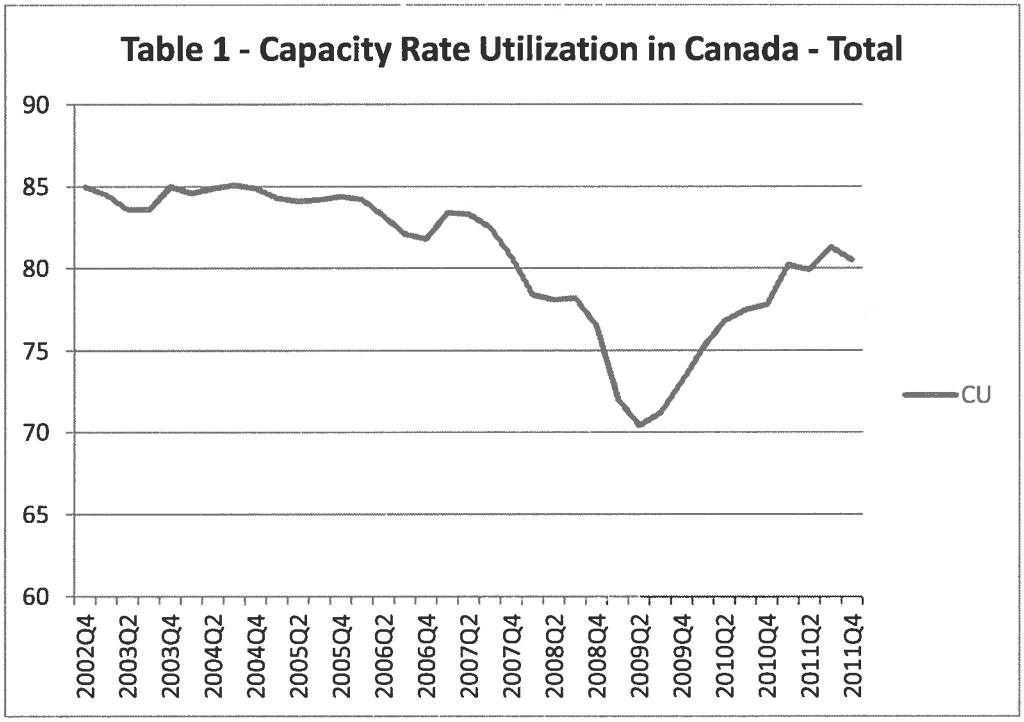
The role of public investment has been widely debated since the post-World War II period. Since the productivity slowdown in the 1970`s, for Canada, U.S.A., and other developed nations, there has been wide debate surrounding the role of public capital and investment with respect to a nation's economic growth. The slowdown has been attributed to slower growth in research and development; a lack of technical progress in key industries; intersectoral shifts of output and labour; the "vintage" effect of newly created capital; and an overall slowdown in infrastructure spending (Gera, Gu, and Lee, 1998). The financial crisis of 2008 caused many governments around the world to adopt stimulus packages, and in many they included infrastructure development funds to generate new economic activity. Given the recent economic stimulus packages in response to the global economic crisis, there remains a strong need to critically analyze the impacts of fixed public capital investments. The main focus of this paper involves Aschauer's (1989a) idea of "core infrastructure," including highways, sewers, water treatment facilities, and other "hard" publicly owned physical assets. This falls in line with the traditional national accounting definition of government fixed capital investment, consisting predominately of non-residential structures, construction, and equipment. By analyzing the development of two unique theoretical and empirical approaches – single-equation production models versus new autoregressive growth models - one can effectively shed light on how a wide range of economic variables are impacted by public infrastructure investment.

The focus of this paper surrounds the public capital hypothesis as described by Conrad and Seitz (1992), which really took hold in the early-nineties when debates about infrastructure development and lagging productivity growth were at their strongest. It posits that public capital will both directly and indirectly affect the productivity of the private economy in a positive manner. Directly, infrastructure development improves intermediate services in private production processes, while indirectly it acts as a complementary spur to private investment. The recent stimulus packages of many developed nations contained specific allocations to infrastructure development, which is the driving factor behind this study – to analyze the various impacts of public capital investment on other economic indicators.

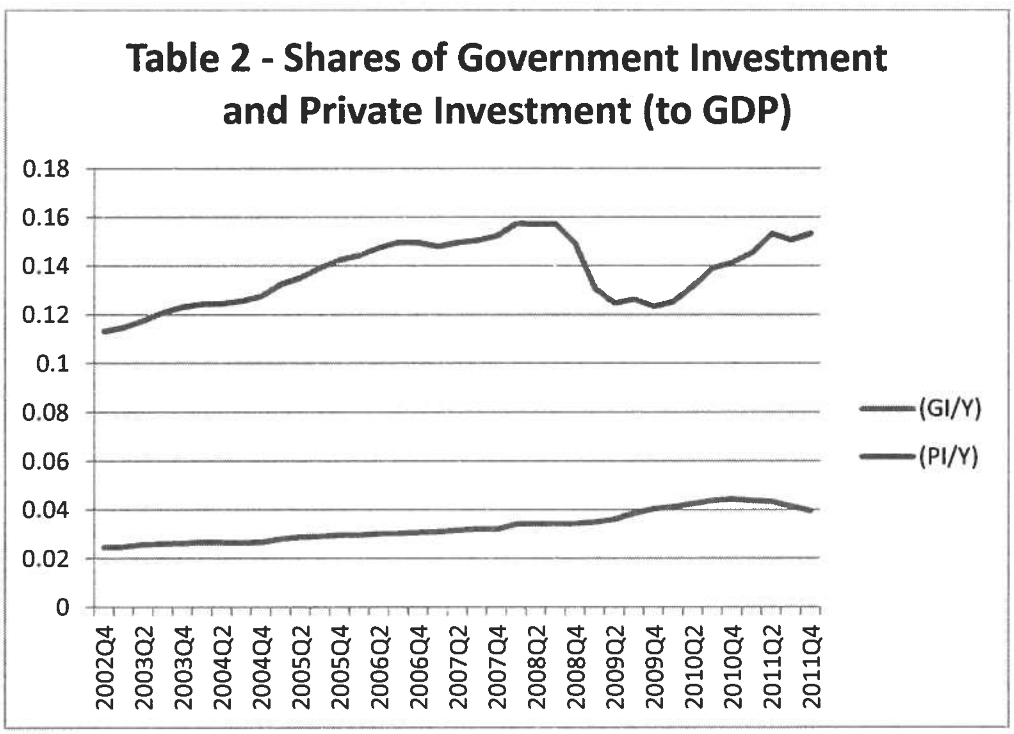
The layout is as follows: section 1) first describes infrastructure development in Canada and in its recent economic stimulus package, and concludes by noting some of the unique characteristics surrounding public capital and its direct and indirect impacts on economic growth. Section 2) briefly explains the neoclassical aggregate production single-equation specification first adopted by Solow (1956), which is the theoretical basis of many influential empirical studies that analyze government capital stock. Specifically we look at the shift from static/level specifications onward to growth models in a theoretical structure that incorporates public capital. This concludes with alternative theories of economic growth, namely of Verdoorn and Kaldor, which differentiate industry-specific growth and expands analyses to include increasing returns to scale. Following this theoretical exposition there is a more refined look at influential empirical studies employing the aggregate production approach. Section 3) engages a similar theoretical and empirical review of cointegration and the more modern vector autoregressive analysis, which endogenizes the single-equation aggregate production framework and opens the possibility of more in-depth multivariate systems. This problem of endogeneity is central to the purpose of the paper - examining whether public investment acts as a complement to private investment. Section 4) is an empirical exercise which uses a modified-Wald test in bivariate autoregressive models, in both level and growth forms, which serves as a basis for future endogenous growth research in Canada. The main purpose is to identify any complementary/substitutionary relationships between public and private capital, and with output – at the provincial, national, and international levels. Section 5) draws from both the literature review and empirical exercise and engages an exploratory policy discussion in the Canadian context. I conclude with the finding that despite there being no apparent complementary or substitutionary relationship between public and private investment in this study, or with employment, public infrastructure growth appears to have a positive impact on output growth in Canada.

Canadian Context & the Unique Nature of Public Capital:

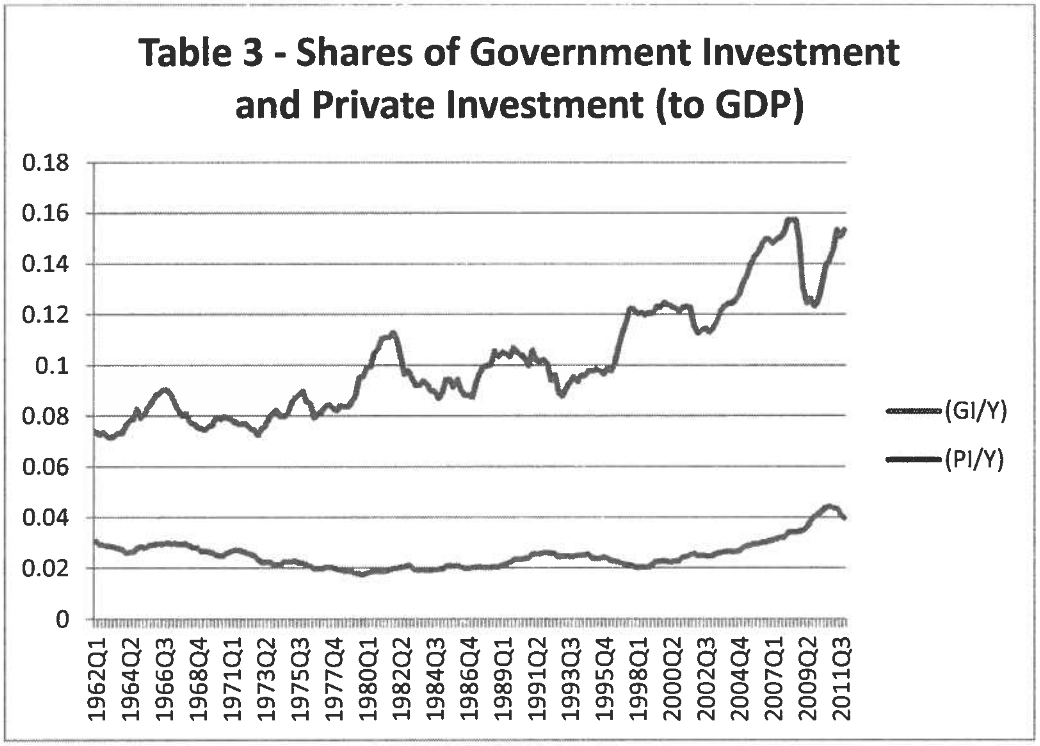
Here my first task is to track the recent trends in Canada's fiscal response to the latest global recession, which can be witnessed in Table 1 in the severe drop in the rate of capacity utilization around mid-2007. Table 2 isolates the last 10 years to display the most recent trends in both public and private investment decisions, measured relative to total output. Around 2008 there is a considerable drop in the relative proportions of private investment. The stimulus package was argued largely on the foundation of Keynesian policy implications, by helping guide the economy through the crisis years by stimulating employment and spending. As such, this paper's task of estimating Canada's historic economic contributions of public investment is important for such fiscal stimuli. Furthermore, as can be seen in Table 3, Canada's share of public investment to output reached its highest level over the last 50 years in 2010Q1, staying above 4% between 2009Q4 and 2011Q3. The relative influx of infrastructure dollars serves as our starting point in discussing the stimulus package and its components.



Statistics Canada (2012), Table 028-0002 - Industrial capacity utilization rates, by North American Industry Classification System (NAICS), quarterly (percent), *CANSIM*, accessed July 25, 2012.



Statistics Canada (2012), Table 380-0002 - Gross domestic product (GDP), expenditure-based, quarterly, *CANSIM*, accessed July 25, 2012.



Statistics Canada (2012), Table 380-0002 - Gross domestic product (GDP), expenditure-based, quarterly, *CANSIM*, accessed July 25, 2012.

Beyond various support to business and consumers to stimulate investment and spending, a large sum of money in the stimulus package was allocated towards infrastructure development across the country. Canada`s federal government initially committed $12 billion over two years to infrastructure development in the stimulus package, which was on top of the 2007 Federal Budget which promised $33 billion to such activities over the following seven years (Flaherty, March 2009). Some projects earmarked for these stimulus funds included the GO Transit system in Ontario, the Evergreen transit line in Vancouver, and initial funds to the Champlain Bridge project in Montreal. In the final report issued in 2012, it stated that $14.5 billion had been federally spent on the Building Infrastructure portion of the stimulus package, with close to $7.5 billion spent on public infrastructure development (as opposed to private residential support). See Table 4 for the breakdown of these funds over the three fiscal years. In total 7, 500 projects were completed, with some success stories including road development in Spirit River, Alberta which was said to not only sustain employment in the area but also built prolonged economic capacity for the Central Peace Region, and in the rehabilitation of parts of the Alaskan highway in Northern British Columbia (Flaherty, March 2012).

This push for government stimulus, both in infrastructure and in other components, was common among G-20 members to counter the financial crisis of 2008. And indeed, most countries increased their government activities, running fiscal account deficits to support these new projects (counter to the monetarist views of the "New Consensus" of the preceding two decades) (Seccareccia, 2012). Policy circles broadly embraced many of Keynes' ideas, albeit for a short-time, under the notion that government activities can generate economic activity in times of hardship. But as can be seen in Tables 2 and 3, this shock to public investments really was a short-lived shock for Canada.

The stimulus spending really kicks in around 2009Q1, but reaches its peak in 2010Q4, and is dropping currently. Furthermore, in 2010Q4 the ratio of public investment to total output stood at 0.044, the highest level since 1962. But many G-20 world leaders in the summer of 2010 argued that their stimulus packages had largely met their goals, and policy focus at the government level should revert back to controlling their deficits. This diametric switch further necessitates the study undertaken in this paper – to try to identify both the indirect impacts of public capital investment on various private factor inputs, and also to uncover its relationship with output. This can help us in understanding how economic activities are related to public investment, and further it can shed light on just how effective these short-lived "Keynes-inspired" projects were. Before engaging our literature review of existing studies on such topics, some unique properties of public capital stock are considered below, which highlights the indirect, endogenous role it plays with other economic factors.

Table 4: Canada's Stimulus Package – *Building Infrastructure* components ($ million)

Investments in Provincial, Territorial, Municipal Infrastructure	2009-2010	2010-2011	2011-2012	Total
Accelerating payments: Provincial/Territorial Base Funding Initiative	179	158		337
Infrastructure Stimulus Fund	525	2,635	807	3,967
Bonus for Community Projects	30	303	163	497
Green Infrastructure Fund	5	42	-	47
National recreation trails	25	-	-	25
Investments in First Nations Infrastructure	87	331	82	501
School construction	82	91	-	173
Water and wastewater projects	69	119	-	188
Critical community services (health facilities)	67	67	-	134
Critical community services (police facilities)	12	3	-	15
Federal infrastructure				
An improved rail system	138	213	-	352
Trans-Canada Highway	16	29	-	45
Federal bridges	39	50	-	89
Alaska Highway	13	-	-	13
Small craft harbours	117	93	-	210
Repair and restoration of federal buildings	171	151	-	322
Enhancing accessibility of federal buildings	16	22	-	38
Manège Militaire in the City of Québec	1	1	-	2
Accelerating action on federal contaminated sites	88	127	-	216
Border facilities	2	20	-	22
Aviation security	343	7	-	350
Total—Building Infrastructure	**2,025**	**4,463**	**1,051**	**7,540**

Flaherty, J. (2012) Jobs Growth and Long-Term Prosperity – Canada's Economic Action Plan 2012, *Tabled in the House of Commons*, Ottawa, ON.

One of the main differences between private and public capital lies in their financing mechanisms and by whom the returns are realized. In the private sense, capital is financed by individuals, and the returns are realized predominantly by them. The case is not as simple for public capital. In Paul Samuelson`s influential work (1954), he defines a pure-public good, or common consumption good, as one which is non-rival (where an individual`s consumption does not prevent simultaneous consumption from another individual) and non-excludable (individuals can not be prevented from the consumption of such goods). While very few goods fall under the pure definition of public goods, infrastructures like highways and clean water and air are typical examples that are cited. As noted by Ashchauer (1990), these government-owned assets serve to maintain (and in some arguments increase) the productive capacity of private individuals. As such, quantifying the returns of these public assets, and to whom they are appropriated, is a fundamentally difficult task.

There are clear difficulties in effectively accounting for and properly appropriating public capital's economic returns, yet infrastructure maintenance (and even further development) remains a necessary government responsibility. Public capital can have indirect impacts on economic growth through a variety of channels. In particular, public capital has been argued as directly impacting economic growth through the "productivity effect," whereby the total cost of producing a certain output level is reduced. Indirectly, there is what is known as the "output effect," which encompasses the process where lower costs lead to lower prices, which can be expected to raise output growth (Harchaoui, Tarkhani, 2004).

While there are many value-laden discussions involving the "proper" role of government and potentials for private substitutability, it is not the goal here. But it is argued that the government's role in maintaining public infrastructure and its fixed capital stock is as strong as ever. Perhaps this responsibility for governments will remain for longer than the provision of other types of public goods and services. The traditional free-rider argument argues against the private provision of infrastructure maintenance and development, built on the idea that such structures would get more "use" than compared to the revenue generated for their upkeep – leading to a Pareto inefficient underprovision (Stiroh, 2000). This paper does not address the feasibility of possible private-public partnerships for infrastructure development, such as joint ownership or toll collection (although it would be of great use).

Aside from these effects of infrastructure on broadly defined economic growth, Aschauer (1989b) and Erenburg (1993) find that public investment can act as a complementary factor to spur private investment, whether it is through stimulating short run demand which indirectly raises private investment, or by wholeheartedly altering the productive landscape in the long term which in turn raises the returns of private investments. Conversely, it is noted that public capital may in fact be a substitute for its private counterpart, because "… the private sector utilizes the public capital for its required purposes rather expanding productive capacity" (Aschauer 1989b, p.186). Trying to account whether Canada's factor inputs are complements or substitutes is the main goal of the empirical section of this paper. Having discussed some main themes that will resonate throughout this paper, we now turn to discuss three specific issues that have been noted when studying the effects of public capital on economic activity and growth.

One of the biggest issues when analyzing public fixed capital, especially when compared to private capital, lies in how to accurately measure its stock and growth. National growth accounting principles have difficulty adjusting for fixed capital that is newly created versus that which is just replacing the depreciated loss. Approximations such as capital consumption allowances try to account for such depreciation, but there are many definitions which make use of different assumptions and estimation methods (Denison, 1957). A second issue with analyzing a country`s public capital lies in just what exactly we consider as capital by definition. Given the diverse and robust nature of public investments, perhaps distinguishing between say highway construction and medical facilities might highlight differences in returns to investment. Throughout the review we will distinguish studies where unique infrastructure developments are considered, but as mentioned earlier the focus is predominantly on "core infrastructure." Lastly, infrastructure improvements are predominantly generated by large lump-sum fiscal decisions, even though the realized benefits intuitively extend well beyond the projects` completion dates and to a variety of individuals (Gillen, 2000). All these factors contribute to immense theoretical and empirical difficulties for measuring the impacts of fixed capital investment on productivity growth.

Single-Equation Production Function Theoretical Foundations:

While the purpose here is not to duplicate the multiple accounts of neoclassical theory, it is necessary to explicate some of the fundamental components of basic single-equation models. Built largely on the work of Solow (1956), the neoclassical approach to growth analysis was grounded in differentiating factor inputs into capital and labour. One of Solow`s fundamental contributions to the field of economic growth was his idea of distinguishing different vintages of capital. In other words, a new machine is ostensibly more productive than the older machine it is replacing – either through the general "wear and tear" factor or if the new machine is technologically superior. He did not distinguish between public and private capital, but the element of old and new vintage intuitively reflects both types of capital. However Solow`s early definition of "capital" was particularly reflective of privately owned capital because of its "rivalrous" characteristic. Many forms of public capital, including highways, roads, and parks, are nonrival in that they can be used by multiple individuals (though realistically, not an infinite number). Thus in Solow`s original form, all which can not be accounted as labour or physical capital falls into exogenously determined technology (Barro, Sala-i-Martin, 2004). Given the shortcomings of Solow's original formulation in analyzing public capital, we now consider a theoretical extension of the model that explicitly accounts for government capital (and its investment).

A number of scholars developed different indices to account for both the stock and flow of government fixed capital. Reviewed here is the simple Solow-extension which includes government capital stock as the third factor input, next to private capital and labour. A relationship between output (Y), the factor inputs private capital (K), labour (L), public capital (G), and the "all inclusive" exogenously determined level of technology (T) can be modelled via an aggregate production function resembling:

$$\boldsymbol{Y_t = T_t * f(K_t, L_t, G_t)} \quad \textbf{(1)}$$

For expositional purposes technology here is described as Hicks-neutral, in that a technological discovery does not augment the ratio of the marginal product of capital relative to the marginal product of labour. However departures to both Harrod-neutral labour-augmenting technological progress and Solow-neutral capital-augmenting discovery are both theoretic possibilities and in some cases clear realities. A more tactile formulation is the traditional Cobb-Douglas structure, which can be quickly altered to an approximated growth relationship by applying natural logarithms and first-differences:

$$Y_t = T_t * K_t^{\alpha} * L_t^{\gamma} * G_t^{1-\alpha-\gamma} \tag{2}$$

$$\Delta \ln Y_t = \Delta \ln T_t + \alpha * \Delta \ln K_t + \gamma * \Delta \ln L_t + (1 - \alpha - \gamma)\Delta \ln G_t \tag{3}$$

$$\text{where } \gamma + \alpha \leq 1$$

While not included here, one can see that that the well known neoclassical production function assumptions are satisfied under this formulation. The important realization from such a production function is that all inputs - private capital, labour, and public capital - are each paid their respective factor shares of national income (i.e. their marginal products – α, γ, and $(1\text{-}\alpha\text{-}\gamma)$). However, this formulation should be read with caution when including public capital because unlike the other two factors, there is no market for public infrastructure. Distinguishing factor income shares is intuitively difficult, because it is impossible for such capital to be "paid" its appropriate remuneration. Though with this being said, much literature is rooted in extensions of this theoretical model using some proxy for infrastructure investments.

Perhaps even more crucial in this theoretical formulation is the point that in a competitive steady-state setting, all factor shares are constant. While in the transitory state these factor shares will fluctuate, neoclassical theory is based on the steady state equilibrium with constant factor shares. Thus if the stock of private capital, labour, and public capital do not grow at all (or more practically where investment only covers what is lost to depreciation and there is no net job creation) the only source of output growth in this model is through technological progress. This point relates to neoclassical models involving total factor productivity growth, $\Delta \ln T_t$, as a key explanatory variable to long-run output growth (in a "steady state" setting). But before addressing into this precarious theoretical entity and structure, let us expand the formulation to capture labour productivity growth and capital deepening effects, which by one definition links equation (3) to an economy`s total hours worked:

$$\Delta \ln \frac{Y_t}{H_t} = \Delta \ln A_t + \alpha * \Delta \ln \frac{K_t}{H_t} + \gamma * \Delta \ln \frac{L_t}{H_t} + (1 - \alpha - \gamma) * \Delta \ln \frac{G_t}{H_t} \quad (4)$$

$$\Delta \ln y_t = \Delta \ln A_t + \alpha * \Delta \ln k_t + \gamma * \Delta \ln l_t + (1 - \gamma - \alpha) * \Delta \ln g_t \quad (5)$$

While this encapsulates labour productivity growth, one could also estimate multifactor productivity (MFP) growth, which measures output relative to a combination of factor inputs (i.e. capital, labour, materials, etc). MFP is not expanded upon here since the technical dynamics of labour productivity fills the void, but MFP is used in some literature reviewed in later sections. In equation (5) the term $\Delta \ln k_t$ represents growth in capital intensity, or the growth rate of capital-per-hour accumulation. Intuitively, one can see that as the capital-to-hours ratio increases, it signifies a relatively higher growth in capital stock versus growth in hours worked ($\Delta \ln K_t - \Delta \ln H_t > 0$). Traditionally this effect is known as capital deepening, because each additional hour worked corresponds to a proportionally higher additional amount of capital being used. The same idea applies to public capital and its deepening effects. The term $\Delta \ln l_t$ represents the change in labour quality ($\Delta \ln L_t - \Delta \ln H_t$), or the difference between growth rate in labour and the growth in total hours worked. Thus growth in average labour productivity, $\Delta \ln y_t$, is directly related to the capital deepening effects of both private and public capital, the changing quality of labour, and the growth in total factor productivity ($\Delta \ln A_t$, which has remained unchanged from equation (3) to (5)). Similar to output growth in equation (3), if the growth of private capital, growth in labour, growth in public capital, and growth in total hours worked are all equal, the only source of labour productivity growth is via total factor productivity, or technological growth.

The implication of technological growth existing as an exogenous factor means that it embodies all other factors not included in this model - which naturally encompass a host of influential factors. This led to two main dissatisfactions with the model. First, scholars grew dissatisfied with a theoretical model that explained sustained output growth via an unexplained, exogenous variable. Furthermore, in Solow's original formulation, significant inputs such as government capital weren't even recognized, and fell under the misnomer of TFP growth. Second, when the model was first implemented empirically (without the government capital stock variable), it was found that upwards of ninety percent of per-capital income growth in the United States of America was attributed to technological progress (Solow, 1957). That so much growth could be attributed to a variable that was not even being measured was a fundamental dissatisfaction with the model, and led to many attempts to widen the included number of factor inputs to include more than simply labour and capital, in particular public investment and government consumption expenditures.

Jesus Felipe and John McCombie (2001, 2003) have also shown that there are serious implications when using aggregation techniques. In one article describing the methodological issues of analyzing the East Asian miracles through an aggregated neoclassical lens, Felipe and McCombie (2003) note that such studies must use dollar values in their estimations instead of physical units of inputs, which imposes an income identity relating aggregate values of output and inputs. Specifically they note that while there may be cases where it is possible for an aggregate production function to be "properly" estimated with a given dataset in applied work, the estimated coefficients must be the factor shares in output. Aside from the implication that coefficient estimates must be the output factor shares, the Solow residual can be similarly modeled as a weighted average of wage and profit growth rates (Felipe, McCombie, 2003, 717-718). Even for cases where the aggregate neoclassical approach works, the income accounting identity means that the regressions must have a high degree of statistical fit and be linearly homogenous in labour and capital.

In describing the problems involved with aggregating economy-wide activities, they cite Solow (1966) himself, noting that "I have never thought of the macroeconomic production function as a rigorously justifiable concept. In my mind it is either an illuminating parable, or else a mere device for handling data, to be used so long as it gives good empirical results, and to be abandoned as soon as it doesn't, or as soon as something better comes along" (1259-60). Ultimately the problem rests with the issue that financial statistics are used in place of physical quantities, and thus the presence of the relational income identity is unavoidable. Dollar values can not capture the heterogenous technological properties of various types of capital and goods (Felipe, Adams, 2005).

Aside from the methodological dissatisfactions above, the neoclassical assumption of constant returns to scale was also challenged by many. In particular

Verdoorn's law (Verdoorn, 1949, 1980) built the foundation of a theory of economic growth that incorporated increasing returns to scale, through a positive relationship between labour productivity growth and output growth. When production expands, it induces embodied technical change by way of new investments that integrate new, better technologies, further expanding production possibilities. In a translation of Verdoorn's original piece, Thirwall (1980, p. 388) writes, "one would have expected a priori to find a correlation between labour productivity and output, given that the division of labour only comes about through increases in the volume of production; therefore the expansion of production creates the possibility of further rationalization which has the same effect as mechanisation." Thirwall (1980) further notes that this correlation may be driven by utilizing economies of scale, by a causal relation of technical progress and output, and by heavy capital deepening effects of expanding industries.

This alternative view of Verdoorn's law was refined by Nicholas Kaldor (1967), who proposed three laws that pertained to economic growth that focused on the importance of the manufacturing sector of a particular country. First he notes that output growth is positively related to growth in the manufacturing sector. This is not simply because manufacturing (dubbed as a country's "engine of growth") represents a large portion of GDP, but also because manufacturing growth induces productivity growth within itself and other industries through embodied technical change. Second he notes a strong positive relation between the growth of manufacturing productivity and manufacturing output. Through increasing returns to scale, this argument is based on static justifications (such that a larger manufacturing industry lowers average production costs) and dynamic rationales (capital accumulation process, embodied technical change, learning by doing). His third supposition highlights the importance of the manufacturing sector, whose growth is positively related to the productivity growth of the primary sector. This is through the process where labour is shifted away from primary industries towards manufacturing sectors. Primary activities typically face decreasing returns to scale, so a reduction in their labour pool necessarily induces growth in their productivity (Thirlwall, 1983). These alternative views will play an important role in my policy discussion section, given Canada's industrial shift from manufacturing to natural resource extraction. The next subsection considers empirical contributions using extensions of the aggregate production function, all of which employ some measure of public infrastructure. This is followed by a similar account of new endogenous growth theory and literature.

Single Equation Empirical Literature:

Some of the biggest contributions to the empirical field of public infrastructure investment came from a series of papers produced by David Aschauer (1989a, 1989b). Initially the literature was significant through its simple use of single-equation Solow modeling and the corresponding significant results that were found. However in short time a number of empirical shortfalls in his methods were realized, and the great impact of his work shifted from his influential results to the controversial methodological approach for using time series data. However his work remains a fulcrum in the broader analyses of public investment and economic growth, and as such must be accounted for. I first consider studies that analyze productivity in level forms (and their subsequent critiques), then move to studies involving growth processes.

Using annual data from 1949 to 1985 from the United States, Aschauer (1989a) uses non-military public investment as "core infrastructure investment" – representing roads, highways, transit systems, airports, etc. He estimates a logarithmic Cobb-Douglas production function in levels, under the assumption of constant returns to scale for all inputs, which relates aggregate private output to a host of factors. One factor included aside from public capital is the capacity utilization rate, employed to control for the business cycle influence (Aschauer 1989a, 182). Though only measuring a static/level relationship, he finds that his measures for core investment have positive and significant impacts on different measures of productivity. In one functional form, a one percent increase in core investment leads to a 0.36% increase in output per unit of private capital (i.e. ln Y/K). His seminal conclusion was that America's post-World War II "golden age" was attributable to substantial core investment in public infrastructure. Here and in other papers he attributes the bulk of the productivity slowdown of the 1970's and 1980's as a direct result of the relative decline in the ratio of public investment to gross domestic product, which had fallen from 1.7% to 0.3% between 1967 and 1985 (Aschauer 1989a, 1989b).

In another pivotal study Munnell (1990a) estimates a similarly static relationship of public capital on the level of labour productivity (i.e. ln Y/L), accounting only for the total non-agricultural sector in the United States over the period of 1948 to 1987. She finds similar significant estimates on her public capital, ranging from 0.34 to 0.41. She too drew many of the same conclusions – that infrastructure investment has a significantly positive impact on private productivity (in a variety of definitions), and that its falling proportions had detracted from growth in the United States.

In following this direction, Munnell (1990b) analyzes state data for the 48 contiguous states between 1970 and 1986 in hopes of identifying regional-specific relationships. Here she found that government capital is statistically significant with output elasticities ranging from 0.06 to 0.15, quite smaller than nationally aggregated estimates. However soon came subsequent critical analyses due to these studies' highly volatile coefficient estimates. One of the biggest critiques was the lack of differentiation of types of public infrastructures. In response to these early studies, Evans and Karras (1994a) use the identical American dataset as Munnell (1990b), and expand analysis by differentiating public capital inputs to include highway capital, water and sewer capital, and other infrastructure capital. They find that in terms of government spending, expenditures on educational services have the most positively significant impacts on output and labour productivity, while other forms of public spending have ambiguous impacts, with the relation sometimes being negative and/or insignificant.

It may now be appropriate to discuss an important policy implication when analyzing public capital and economic performance. Between some of these early studies (Munnel, 1990a, 1990b) and the empirical critique of Evans and Karras (1994a) one can see that when analysis is drawn closer to the local level (i.e. state/provincial level, county/municipal level), estimates indicate that the impact of public infrastructure investment is much smaller than at the aggregate level. Infrastructure investments at the local level appear to act in a manner that redistributes economic activity, rather than generating any net growth (Gillen 2000). A study by Chandra and Thompson (2000) restricts analysis to interstate highway construction for counties across the continental United States. Their findings were such that highway construction has a differential impact across both industries and jurisdictions. Specifically, certain industries may grow as a result of new highways, but the relationship is ambiguous for other sectors. But even more interesting were their findings on the spatial distribution across county jurisdictions. Communities which were physically close to these highway developments saw an increase in the level of their economic activity, whereas adjacent communities actually saw a drop in economic activity, leaving the "net level of economic activity unchanged in non-metropolitan areas" (Chandra and Thompson, 2000, 487). That public infrastructure investment may be more productive for certain industries, as well as for specific communities and regions, will be discussed in the concluding policy section.

Let us now shift focus onto Canadian-specific studies which use this approach of estimating productivity relations in level terms. In following Aschauer (1989a) and Munnell (1990a), Wiley (1996) similarly builds a model measuring public infrastructure's impact on the level of labour productivity (i.e. ln Y/H) for Canada`s goods-producing sectors. When infrastructure was only defined as total publicly-owned capital, its influence on the level of productivity was significant with an elasticity of 0.407. In fact, public infrastructure shows up to be significant in all regression specifications attempted, with a fairly stable elasticity of output-per-hour of between 0.407 and 0.436. He goes on to differentiate between core infrastructure and fixed capital consisting of hospitals, education facilities, and other similar institutions, which yields significant estimates of 0.299 and 0.112 respectively.

However another critique from these early studies came from Evans and Karras (1994a), who outline the shortcomings of Aschauer (1989a) and Munnell (1990a), specifically that "..a positive and statistically significant coefficient for a government input in an estimated 'production function' may only indicate the degree to which increased income generates the increased level of government activities" (p.2). This basically covers the case of two-way causality (i.e. perhaps increased income generates increased infrastructure spending by way of increased tax revenues). Furthermore, it has been noted that these empirical formulations are likely misspecified because of the fact that they are estimating the production function in levels, when the data displays signs of stochastic trends (Hulten and Schwabb 1991; Evans, Karras 1994b). Spurious regression results led to inflated coefficient estimates, likely from the non-stationarity of data used. As such, the modified-Wald test used in the empirical section of this paper is applicable whether data series are stationary or non-stationary.

The remainder of the aggregate production account will focus solely on studies analyzing growth, contrasting but equally complementing the studies above which analyze output and productivity in level terms. The pivotal study by Aschauer (1989c) uses panel national accounting information from the Group of Seven from 1966 to 1985. Here he analyzes the impacts of core infrastructure on labour productivity growth (i.e. $\Delta \ln(Y/L)$). Using this panel data and staying within the neoclassical domain, he estimates that public non-military investment has a positive and significant impact on labour productivity growth in a variety of model specifications. The variance of his estimates for core investment is quite large depending on the production function being specified – ranging from 0.73 to 0.34. Private investment also has significantly positive estimates, though considerably smaller at 0.12 to 0.22. Another one of the fundamental contributions of this particular work was the distinction made between public investment and public consumptions expenditures. Government consumption spending has a significantly negative marginal relation on labour productivity growth (-0.13). Though as mentioned earlier while these results were initially welcomed with great excitement, a slew of critiques arose which put into question the validity of the statistical techniques used.

First came from his definitions of both public and private investment. In his 1989b study, both statistics were of the form: gross fixed capital accumulation minus consumption of fixed capital, relative to gross domestic product. Evans and Karras (1994b) note that Aschauer's estimation equation is only valid based on the assumption that the ratios of net capital growth to output are constant across the sample. They note that assumption is very untenable for a single country, as the ratios have varied considerably over time, let alone his panel of countries. Secondly Aschauer's work did not include random or fixed time and country-specific effects, which account for recurring realities like business cycles and unpredictable events such as natural disasters. These two dissatisfactions led to the study by Evans and Karras (1994b) that reengaged the panel of countries from Aschauer's G-7 study with data from 1963 to 1988, and found that misspecifying the production function by ignoring these controls can have serious implications. Further, they note that "Under the most plausible specifications, the estimates [of the coefficient of public capital] are not statistically significantly different from zero at conventional levels" (Evans, Karras, 1994b, p.277). That such estimates are extremely fragile under different model specifications is reason for concern. They conclude that public investment is neither highly productive nor underprovided in the Group of Seven.

Similarly the study by Sturm and Haan (1995) reevaluates the study by Aschauer (1989a) by applying first differences to the original data set. They found no consistent, economically interpretable results. They first note that non-growth studies employing time series that are neither stationary in levels nor cointegrated in the long term typically generate obscure, imprecise elasticity estimates. Estimates for the impact of core infrastructure for the USA, in addition to the elasticities of private capital and labour, were deemed too peculiar to fit any sort of rational economic theory. They conclude that the single-equation aggregate production function approach is built on "fragile statistical foundations," and that the complementary microanalytic "cost function approach might be useful here." (Sturm, Haan, 1995, p. 66).

In a Canadian context, Khanam (1996) analyzes the impact of highway development on the Canadian economy from 1961 to 1994. Here she uses pooled data and provincial data from across the ten provinces, and uses a variety of functional forms including accounting for time and province-specific effects. In her standard Cobb-Douglas-growth formulation, she finds a significant coefficient estimate for public investment growth on output growth of 0.17, but when controlling for time and province effects leaves an insignificant estimate of 0.09. Results are positive but clearly highly volatile to differences in model specifications and underlying assumptions. Furthermore, Khanam (1996) concludes that aggregate production techniques are not exhaustive in identifying direct and indirect effects of public infrastructure, and notes that with the exception of British Columbia and Ontario highway capital appears to have decreasing contributions to output growth over time. This endogeneity issue of indirect effects is the main benefit of vector autoregressive techniques outlined in the second half of this literature review. Given their propensity of generating volatile estimates, she notes that policymakers should not blindly start investing in infrastructure based on such aggregate production frameworks (Khanam, 1996, p. 265), but should perhaps use this method in conjunction with a complimentary approach, such as a cost function method or new growth method.

It is quite clear that studies involving public investment, especially in terms of core infrastructure development at both the international and Canadian level, have faced numerous methodological hurdles which have led to highly variant, dissimilar conclusions. The single equation aggregate production approach falls short (in one way) by not realizing the interrelated nature between factor inputs, and even between these inputs and the hypothesized "output." New endogenous growth theory with its vector autoregressive modelling grew largely out of the dissatisfaction from the fragility of single equation aggregate production frameworks, and specifically the interrelations that exist between factor inputs. We now turn to our review of new endogenous growth theory.

Autoregressive Endogenous Theoretical Foundations:

Distinguishing the impacts of timely, drawn-out public infrastructure investments is difficult because of specification issues in the single-equation production framework outlined above. One of the driving factors behind endogenous growth literature dealing with the impacts of public infrastructure development is to account for some of the internal relations that exist between separate "exogenous" variables in the aggregate framework outlined above, which allows for more in depth analyses of interrelated variables. Also, the single equation approach was restricted by its model specification, whereas autoregressive techniques impose little structural constraints. I now briefly address some of the technical foundations on which public capital autoregressive growth literature is founded upon.

One common issue with employing ordinary least squares (OLS) estimation on time series data, like many of those studies outlined earlier, can be identified in the generated error terms. Error terms are assumed to have zero means [$E(u_t)=0$]; have constant variances [$E(u_t^2)=\sigma^2$]; be uncorrelated with their past values [$E(u_t,u_{t-i})=0$]; and be uncorrelated with any exogenous variables [$E(u_t x_t)=0$]. If such properties hold with a particular time series, then OLS will lead to the best linear unbiased estimates of parameter coefficients. However in reality, and in the data analyzed in this paper, such strong assumptions do not hold. For instance, there is strong autocorrelation found in the residuals of simple OLS estimates using this data, and also the possibility of colinearity between variables and error terms. In models where so many variables are interrelated, error terms rarely capture pure "white noise." This leads to an underestimation of standard errors and artificially high t-statistics of significance for the estimated coefficients (Harris 1995). Such problems necessitate the use of other more modern approaches, such those which utilize cointegration modelling.

Cointegration refers to a situation where two or more time series share a common stochastic drift, such as the paths of private and public fixed capital investment. This was formalized by Granger (1981) and others, who directly addressed the common problem of spurious correlations when employing OLS estimation on time series data. Outlined here is the Johansen (1988) method of testing for cointegration, due to its use of vector autoregressive techniques and multivariate capacity. In spite of this paper's empirical section which makes use of bivariate autoregressive frameworks, it can be extended using the Johansen technique to build multivariate analyses, making this a worthwhile exposition for future research in endogenous growth.

The Johansen cointegration test is based on a vector autoregressive (VAR) model. One form of the Johansen cointegration test is in the unrestricted VAR specification below

$$z_t = A_1 z_{t-1} + u_t \quad (6)$$

$$\Delta z_t = (A_1 - I) z_{t-1} + u_t \quad (7)$$

$$\Delta z_t = \pi z_{t-1} + u_t \quad (8)$$

$$\text{where } \pi = (A_1 - I)$$

This specification is a system of n variables, where z_t and u_t are vectors of size (n X 1), A_1 is a matrix of (n X n) parameters, and I is an identity matrix of size (n X n). Constants and time trends can be included in the Johansen test, though they are not included in the above notation. The matrix π produces linear combinations of variables in vector z_t, but not all these relationships can be cointegrated. To be brief, cointegration implies a restriction on π's rank, such that the number of maximum possible unique cointegrating vectors in a system of n variables is (n-1). If at least one cointegrating relationship is present, we can apply a vector error correction model (VEC) to our basic VAR system, allowing us to measure long and short run adjustment components (Greene, 2012). Thus if r=0 under the test, it is found that there are no cointegrating (long run) relationships among the variables and only adjustment (short run) processes can be estimated.

The basic premise of this model is that cointegration relationships are used to model the long run impacts of variables under study. It is largely thought that the impacts of factor inputs like public infrastructure ought to be realized in the longer term than in the short run, making cointegration a desirable method. Thus while not of direct use in this paper's empirical undertaking, it is worthwhile to account for the possibility of long run relationships, especially given the literature review to follow. If a set of variables test positive for one or more cointegrating relationships, the error correction model takes the form:

$$\Delta z_t = \alpha + \Pi z_{t-1} + \sum_{j=1}^{p-1} \Gamma_j \Delta z_{t-j} + \varepsilon_t \qquad (9)$$

Π represents the long-run cointegrating relationships of the lagged endogenous variables in level form, whereas Γ_j represents the short run dynamics of the endogenous variables in first-differenced form. As can be witnessed, the short run dynamics in these endogenous models are driven by first-differences (or growth rates if logarithmic first-differences are used), whereas long-run relationships are captured in level forms (Johansen 1998). This technical overview lays the foundation for both the proceeding account of modern studies and my empirical section which engages bivariate autoregressive models, the most basic structure of VAR and cointegration analyses. The modified-Wald test used in our empirical exercise is valid in both the presence and absence of cointegrating relationships, unlike standard F-tests. One must simply account for the maximum order of integration in each of the bivariate systems (Toda and Yomato, 1995). However before turning to our autoregressive empirical exercise, we review some of the influential literatures using public infrastructure investment in autoregressive models.

VAR Empirical Literature:

Vector autoregressive cointegration literature is largely driven on the issue of endogeneity between variables under study. In breaking down endogenous relationships, empiricists aim to discern some of the interrelated externality relationships that may exist. A study by Sin and Lau (1997) engage the Johansen cointegration model using American data from 1925 to 1989, with the main intent of examining the importance of public infrastructure in the growth process of the USA. By using a natural logarithmic specification of output, private capital, labour input, and public capital, their study is a good starting point for comparing this approach to the single-equation findings of Aschauer (1989a) and others. They find the output elasticity with respect to public infrastructure to be 0.11, which they note is much smaller than similar studies employing single-equation methods (Sin and Lau, 1997, p.132).

In another American study specifically challenging the unrelated, exogenous assumptions of variables in single-equation aggregate production frameworks, Pereira and de Frutos (1999) maintain that endogenous, dynamic relationships are integral in such analyses. They find that public capital endogenously follows a policy rule where it acts as a counter-cyclical tool with employment, implying that infrastructure investment rises when lagged employment falls. However, they find that after accounting for the dynamic effects in the model, employment responds to changes in public capital formation with a long-term accumulated elasticity of 0.04, implying that it takes on average $630,000 of accumulated public infrastructure to create one private sector job. Similarly, in estimating the interrelationship between public capital and private capital, they find that a one dollar capital investment generates $0.78 worth of private capital in the long-term, though no meaningful reverse relationship was found. In moving from the endogeneity among factor inputs to the impacts on output, they find that a one dollar capital investment leads to a $0.63 rise in long-term output. They conclude by noting that while their model shows how public infrastructure is productive on other variables including output, the short-run policy implications of using infrastructure development as a tool to address falling employment may be a particularly bad policy. This is because the difference between the policy decision and its actual implementation, and they note specifically that "..public works actually take place when they are no longer needed, i.e., close to the peak of the business cycle, and that the short-term public investment plans rarely coincide with or satisfy the long-term needs of infrastructure development." (Pereira and de Frutos, 1999, p.320). Though productive, the timeliness of infrastructure projects might make them undesirable if their purpose is to address short run fluctuations in employment. Not surprisingly, this is discussed in the concluding policy section.

Keeping this focus of infrastructure investment as being endogenously guided by a policy rule, it is worthwhile to review other rationales that can be used to guide public investment. A study by Pereira and Andraz (2005) first analyzes the dynamic feedback relationships between public investment in transportation infrastructure and other traditional factor input for Portugal. Similar to the study above, they find that public capital has a productive influence on private capital. In particular, they note that the largest impacts on private investment come from accumulation in ports, airports, and national road systems. They further find that in the long term, additional public investment crowds-in employment, with the largest impacts coming from ports and municipal roads. In terms of identifying a policy rule to guide public investments, they find that a one Euro rise in public investment leads to a 9.5 Euro increase in output in the long term, corresponding to a return rate of 15.9% (Pereira and Andraz, 2005). They note that over the course of a particular infrastructure's life span, the increased tax revenues from output growth not only pay for most of these projects, but also generate additional revenue by way of an increased tax base. While it might be dangerous to put all one's faith into this policy rule, it is worthwhile to note that at least in the Portuguese context, infrastructure investment can be argued through both the lens of traditional long-term development and long-term public budgetary realities (Pereira and Andraz, 2005, p.177).

In keeping this focus on European regions, a study by Mamatzakis (1999) analyzes the long run relationship between public capital and private capital productivity for Greece. He uses a rather broad definition of public capital, including all ports, railways, motor vehicles, civil aviation, roads, electricity, and communications, so as to try to capture the wide-ranging impacts these public assets hold. In the long term, a positive relationship is found between public capital and private productivity, such that a one percent increase in infrastructure leads to a 0.25% increase in private capital productivity. They further note that the reverse-causation feedback effect from private capital productivity to public infrastructure is rejected under their specification.

Despite the general conclusion that public capital is productive to a region's economy, there are clear deviations in findings among research reviewed here, even among countries with similar geographies, histories, and political-economic structures. Shifting focus back to the Western hemisphere, it may be worthwhile to review some literatures from South America to see if there are any common trends, especially since many countries there have seen drastic shifts in the sizes and roles of their governments over the twentieth century. A study by Albala-Bertrand and Mamatzakis (2001), following very much the same approach as Mamatzakis (1999), aims to model the impacts of public infrastructure on output in the Chilean context. Using data from 1960 to 1995, which spans diverse political stances by this respective government, transportation and other fixed public capital were found to have significantly positive long-run impacts on output. Specifically, they find that a 10% increase in infrastructure expenditure leads to a 2% rise in output over the long-term. Furthermore they find that while this unidirectional causal relationship appears, the reverse-relationship of output on public expenditure does not appear to be very robust. Among factor inputs in the short run, they found that the public capital hypothesis is supported, specifically that public capital crowds-in private capital.

A Mexican case study undertaken by Ramirez (1998) was built largely under similar auspices as previous autoregressive studies considered here. Using data spanning 1950 to 1990 and after accounting for oil boom years (1978-81) and economic crisis years (1982-83, 1986-87), he finds that growth in both public and private fixed capital have significantly positive impacts on labour productivity growth (0.40 and 0.52 respectively). He uses a measure of government consumption expenditure to differentiate the functionality of various public spending, and finds its lagged short run growth has a significantly negative impact (-0.07) on labour productivity growth. He concludes by noting that his results are more reflective of the need to reallocate public spending, not to increase all its factors absolutely. Cash-strapped governments, such as Mexico following the peso crisis of 1994-95, should proportionally lower spending on consumption type goods, which can compete with private sector alternatives, and increase investment on public goods such as infrastructure.

Despite the lack of Canadian-specific studies, one can first look to Australian studies not only for the historical similarities it shares with Canada, but also because of its similar dispersion/concentration of population along border areas. Otto and Voss (1996) use quarterly national accounting data from1959:3 to 1992:2, and find cointegration to be present among various combinations of factor inputs. With a particular focus on the broad critique that aggregate production functions generated estimates that were implausibly high, they find that in the long run, the output elasticity for labour, private capital, and public capital are respectively 0.44, 0.39, and 0.17. They note that such estimates are more rationally interpretable than previous studies. Their short-run analysis concludes that both types of capital stock positively affect output and that public and private investment complement and crowd-in each other. Their strongest evidence is that public investment is highly responsive to private investment, and slightly weaker evidence supporting the reverse relationship (Otto and Voss, 1996, p.735).

Another study by Voss (2002) considers American and Canadian data to try to identify patterns of crowding in-or-out between public and private investment. One of the driving reasons for this study was to identify any differences that exist between large open economies (i.e. USA) and small open economies (i.e. Canada). It was hypothesized that from a public capital shock the USA would see crowding-out in the short run, due to private agents responding to this over-optimal national investment by lowering private investments. This would eventually lead to some degree of crowding-in in the long run, depending on the productive nature of the public investment. Conversely, he hypothesizes that Canada would face crowding-in in both the short and long terms, as long as high capital mobility is present. For American data, there is strong evidence of crowding-out between both sectors in the short run, but little evidence for crowding-in in the long run. While there appears to be a small degree of crowding-in for Canada in the short run, the impulse response function identifies this is followed by strong trends of crowding-out. And furthermore, Canada too did not see consistent crowding-in in the long run. He concludes by noting that between these two countries the accelerator effect of public capital is negative, and that further research should be done to analyze the decision making processes of public investment decisions (Voss, 2002, p.662).

To conclude this autoregressive review we look at a study by Mittnik and Neumann (2001), who test the public capital hypothesis using a panel of six industrialized countries – Canada, France, Great Britain, Japan, the Netherlands, and Germany. Three out of these six countries (Canada, Germany, the Netherlands) demonstrate that public investment generates private investment, indicating the public capital hypothesis holds and the complimentary relationship exists. No case demonstrated the crowding-out effect, where public investment was a substitute to private investment. Overall, they find evidence that suggests that public investment has a positive influence on output, and furthermore the interrelations between factor inputs demonstrate that public infrastructure is best measured in an endogenous, autoregressive framework. Having concluded the review of endogenous literature, I now engage my empirical exercise which tests the public capital hypothesis among others, at the provincial, national, and international levels.

Empirical Exercise:

This exercise aims to serve as a foundation for further applied research in the domain of endogenous growth, and follows the approach and specifications of Sturm (1998). While not fully engaging multivariate specifications, this method allows us to address the dynamic relationships between various factor inputs, which is one of the major shortcomings of single-equation specifications. Taking into account the endogeneity problems of the aggregate production function, this section moves forward with tests of Granger non-causality in a number of bivariate vector autoregressive relations using modified-Wald tests. Testing various combinations can help shed light on any unidirectional relationships that may exist between such variables. First we outline the methodological approach, which flows directly from the account of vector autoregression above. Then we move on to the formulated hypotheses which will be tested.

The first task in such an autoregressive analysis is to determine the order of integration of each series used. To do this, I use the Augmented Dickey-Fuller test utilizing Akaike Information Criteria (AIC). Though the technical specifications of this test are not included here, the order of integration is required as this is the number of additional lags to be included in the VAR. Consider equation (10), a 2 variable VAR(p) system, where p represents the optimal number of lags in the system:

$$\begin{pmatrix} x_t \\ z_t \end{pmatrix} = \begin{pmatrix} a_{10} \\ a_{20} \end{pmatrix} + \begin{bmatrix} \Psi_{11}(L) & \Psi_{12}(L) \\ \Psi_{21}(L) & \Psi_{22}(L) \end{bmatrix} \begin{pmatrix} x_t \\ x_t \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} \qquad \textbf{(10)}$$

Here (L) represents a lag operator such that $\mathbf{x_t(L) = x_{t-1}}$. Furthermore it should be noted that $\mathbf{\Psi_{ij}(L) = (\gamma_{ij1}(L) + \gamma_{ij2}(L^2) + \ldots + \gamma_{ijp}(L^p))}$, and that ε_{it} are assumed to be white noise with a constant covariance matrix. In its typical form, x does not Granger cause z if we do not reject the hypothesis that all $\boldsymbol{\gamma}$ in $\mathbf{\Psi_{12}}$ take a value of zero. However when data is non-stationary (i.e. integrated of I(1), as is the case with most time series) standard asymptotic theory is not applicable to the above hypotheses. Similar problems arise if the data contains a cointegration relationship. Thus, we employ methods of Toda and Yomato (1995) and their modified-Wald test, which is applicable whether the VAR is stationary or integrated of an arbitrary order. Importantly, unlike standard F-tests the modified Wald test remains significant even when series are integrated/non-stationary, as is described below. In the formulation above, to test that $\mathbf{z_t}$ does not Granger cause $\mathbf{x_t}$, we test the parameter restriction $\mathbf{\Psi_{12}=0}$. Under the null of non-causality, each system has an asymptotic χ^2 distribution for hypotheses testing.

The premise of this VAR-causality specification is that once an optimal lag length p has been determined, which is governed here by using AIC, a VAR of a $(p+d)^{th}$ order is estimated where d represents the maximum order of integration contained within the system as determined by the ADF test. Once this system is estimated, the p-lags are tested against the null hypothesis of non-causality. As long as the order of integration does not exceed the optimal lag length, then standard likelihood criterion can be applied to the first p coefficient matrices to determine Granger non-causality (Toda and Yomato 1995). Thus, in odd cases where a series is I(2), the optimal lag length determined by the AIC must be equal or greater than 2.

One well-known shortcoming of such an exercise is that causality may be found to exist when in reality each pair of variables is driven by a third relationship to a variable which is not included. This is of particular importance for macroeconomic studies, which often engage interrelated variables whose dynamics are rarely clearly defined. Furthermore, this analysis focuses on short-run dynamics, whereas public capital may be best suited for analyses in the long run. Thus in the event no meaningful relationships are found in this dual context I engage the Johansen cointegration test with Canadian data, which identifies any long run relationships that exist in a multivariate system. This serves as a platform for more complex error correction and impulse response analyses.

As mentioned earlier the public capital hypothesis is the fulcrum of this exercise – trying to identify whether public infrastructure investment acts as a complement or substitute to other factor inputs and output. Aschauer (1989c) and Erenburg (1993) provide theoretic rationales and empirical support for both these oppositional cases. As demonstrated by the nature of Canada's stimulus package in the recent economic downturn, there is reason to believe that public infrastructure investment is thought to have at least some direct and/or indirect impacts on economic performance and development. The following hypotheses try to identify any trends at the national, provincial, and international levels.

Following the bivariate approach of Sturm (1998), hypotheses set (1) tests the public capital hypothesis at the national level, which tests the causal relationship of public on private investment (i.e., if public investment creates a more constructive environment for private investment) along with its backward-linkage case (i.e., private investment generates public investment – perhaps through taxation revenues arising from private capital investment). Though the main purpose of this paper focuses on fixed capital investments, set (1) tests the relationships between both public and private investments and employment and total hours worked. It may also be worthwhile to test the relationship of public capital investment with the differentiated private investment in non-residential structures and that in machinery and equipment. There may be reason to believe that public investment, which consists largely of infrastructure components, might be more conducive to business construction of structures. But equally, perhaps infrastructure development might make it more favourable for machinery and equipment, such as big trucks and excavation equipment in the transportation and natural resource sectors. It would be ideal if the accounting principles broke down public investment into more refined components, but that is not the case. Thus we test the level and growth relationships between these refined private investments, public infrastructure, and output using quarterly data from 1962 to 2011. Furthermore, I test the relation of these factors on output, and on labour productivity. This type of interrelation analyses is reflective of a multivariate VAR system, by analyzing the endogenous relationships among factor inputs. Hypothesis set (1) is included in Appendix 1.

All hypotheses are engaged in both level and growth forms, using Canadian aggregate data from 1962 through 2011. Data was compiled from Statistics Canada's

CANSIM database, the Labour Force Survey, and the Historical Statistics of Canada compilation. Moving from this national lens, I shift focus to the provincial scale, given the studies of Evans and Karras (1994a) and Chandra and Thompson (2000). Though data is limited to 1980 through 2011, I test the public capital hypothesis among the 10 provinces in both level and growth form, and also test the relationships between public capital and output. Set (2) is summarized in Appendix 1.

Hypothesis set (3) engages the public capital hypothesis at the international level, using data accumulated from the national accounts of the respective states. It is hoped that if no consistent relationships are identified in the Canadian data, then perhaps other countries with different geographic, cultural, and politico-economic makeups might demonstrate differing results. All countries tested here had specific expenditure variables for public investment, which excluded residential structures from their private fixed capital investment data. Again these are completed at both level and growth forms. Following this, we test my last hypotheses set (4), which similar to set (3) breaks down American data into a more refined analysis. American data has the historic breakdown between federal and state investment, so this differentiation is examined. Hypotheses sets (3) and (4) are included in Appendix 1. We can now turn to the analyses of the preceding hypotheses.

Empirical Analysis:

Each series is estimated after applying natural logarithms, constant, and a time trend. Before analyzing our causality results, I must first consider our stationarity tests to determine the maximum order of integration that will be present in each respective system, or equally the number of additional d-lags must be added to each system. I first apply the ADF test using Akaike Information Criterion to each time series in their level terms, and if it fails the stationarity test I apply the ADF test to the series in first differences, and second differences otherwise. The results of these tests are found in Appendices 2 through 6. Natural logarithms are applied, as are constants and time trends. Most series are identified as I(1), a small number are I(0), and a few are I(2). To be specific, the second-difference stationary series are B.C. output, Newfoundland public investment and output, P.E.I. output, France output, Germany output, and New Zealand's private investment and output. These series must be highlighted, because if any one is included in a bivariate model whose optimal lag length is one, the modified-Wald test is no longer valid.

Appendix 7 contains the results of hypotheses set (1). As can be seen, there are no strong causal relationships identified among traditional factor inputs (i.e., investments and labour), in either the level or growth form. The only relationship among factor inputs at this national level is the unidirectional association between growth in hours-worked on private investment growth. With an optimal lag length of 2, each lagged coefficient takes an opposing sign, though the sum of the two is positive. If there were stronger trends in the signs of the coefficients, then there would be more evidence supporting whether the factor has a negative or positive causal relation.

I also differentiated between different private investments in non-residential structures and machinery/equipment. Between private investments in non-residential structures and machinery and equipment at the level form, no causal relations with public investments are identified. But when we look at the level relationships between these factor inputs and output, some causal relationships are identified. First, unidirectional causation is identified running from from output to public investment and from output to private investment. Again these regressions are in log-level form making interpretation difficult. Dual causation was identified between output and total fixed private investment, and output and private investment in machinery and equipment.

In terms of growth patterns, the only causal relationships with output were of a dual nature, and they were found between output and all factor inputs being analyzed. This indicates that all these variables not only impact and shape economic output growth, but are also endogenously impacted by this growth. This gives credence to the argument for more in depth multivariate analyses, which accounts for such interrelations among all variables under study. Thus the following section tests for long-run relations with a Johansen cointegration test. With a lag length of one, public investment growth takes a coefficient value of 0.048 on output growth, while output growth coefficient takes a value of -0.042 on investment growth. These indicate that increases to government investment will cause output growth, but conversely investment growth decreases as output growth rises – reflecting the policy alignment of functional finance. Conversely, the sign for private investment growth on output growth is 0.066, while the reverse causation sign is 0.084, telling us that while private investment growth builds output growth similar to public investment, output growth conversely generates private investment growth. This is in line with policy behaviours that see public investment fall in times of economic prosperity. However, no causal relations are found between public investment and labour productivity (as defined as (Y/H)), while the form (Y/N) could not be tested since the optimal lag is 0 and the maximum order of integration among the variables is 1.

So while the short-run analysis above only identifies relationships between certain factor inputs and output, Appendix 8 presents the Johansen cointegration tests for multivariate systems using Canadian data. As mentioned earlier, cointegration implies long-run comovement among a combination of variables. I have included output as the `dependent variable` first (although all variables are endogenous in this form), and labour productivity in the second half. All tests were conducted using a set lag length of 5, with trend and constants in the cointegrating equation. Except for the combination of labour productivity (in both forms), government investment, and private investment, all combinations test positive for at least one cointegrating equation at the 5% significance, indicating the presence of long-run relationships. That being said, it should be noted that those 2 combination sets which did not test positive both passed the 10% significance level. Thus despite no strong short-run dynamics identified via the modified-Wald test, the Johansen cointegration test indicates combinations of these variables are related in the long-run.

Appendix 9 demonstrates the short-run provincial exercise undertaken here. Unlike those time series above, all of which are either I(1) or I(0), there are series from British Columbia, Newfoundland, and Prince Edward Island that are second-difference stationary. The tests for the public capital hypothesis identified no consistent causal relationships at either levels or growth rates, though all tests were valid in the modified-Wald context because the optimal number of lags generated by the AIC was greater than or equal to the maximum order of integration in each bivariate system. However, when we look at the relationships between provincial public investments and provincial output, there are a number of systems which do not align with methodology. In the level relationships, the British Columbia case could not be estimated because their public investment was I(2) but the optimal lag was one. Among the ten provinces, three cases (New Brunswick, Nova Scotia, and Saskatchewan) face a unidirectional relationship of public investment on output, while Prince Edward Island has a dual impact. While the signs of the unidirectional coefficients under the null hypotheses are negative, which indicates that as public investment rises output falls, the fact that the study is log-level makes it difficult to interpret further.

In terms of growth, AIC identified a number of bivariate systems whose optimal lag length is zero or one, invalidating the modified-Wald test for a number of provinces with I(1) and I(2) series. Of the valid systems, Nova Scotia and Ontario have unidirectional relations from public investment growth onto output growth. P.E.I. and Saskatchewan have unidirectional relations from output growth onto public investment growth, with opposing signs on each. Due to the inconsistent results witnessed at the differentiated geographic lenses, I decided to differentiate types of private fixed capital at the national level, in hopes that unique capital types might demonstrate more consistent complimentary relationships with public investment.

Appendix 10 analyzes our international subset. As mentioned earlier, those series which were second difference stationary (i.e. I(2)) were France output, Germany output, and New Zealand's private investment and output. These series can be potentially problematic if the optimal AIC-lag length is one or zero. No dual causality was distinguish in the level relationships between public and private capital investment, although four countries (Australia, France, Korea, and New Zealand) face one-way causal relations from private to public investment, with Germany only showing public-to-private causation. In terms of growth relationships of investments, there appears to be some degree of one way-causality running from private to public investment growth rates (Finland, France, New Zealand - though the signs of these relationships are ambiguous, not telling us whether the public investment relationship with private investment is functional in the sense of "functional finance").

The relationships between public investment and output similarly generate ambiguous results. New Zealand's level relationship could not be estimated because the order of integration exceeds the optimal lag length. The investment-to-output relationships in five countries (Finland, Netherlands, Germany, Korea, and The United Kingdom) demonstrate one-way causality from output to public investment, though there are ambiguous signs between different lag lengths and countries. The growth relations of France's, Italy's, and Korea's output-and-public investment relationships could not be run because integration order exceeded the AIC optimal lag length, and the only other significant results indicated opposing one-way causal relations. Once considering the ambiguity of results from aggregate statistics from the provincial, national, and international levels, it is judged that refined accounting measures used in hypotheses set (3) for Canadian data seem like the most appropriate way in moving forward with such analyses. Thus the final Appendix 11 engages American data in a geographically refined manner similar to Canada`s exposition above.

Appendix 11 breaks down American public investment into total, federal, and state spending. As can be witnessed in the international comparison, total public investment is seen to have a unidirectional causation on total output, in both level and growth forms. When this is broken down into federal and state spending, at the level form it is witnessed that federal investments have no relations, but state investment spending is of a dual nature. When I analyze the growth relations of federal investment growth on output growth, we see that there is a one way relation running from output growth to federal growth, though the 8 lagged coefficients generate considerable variations in their signs, with no consistency over time. Conversely, state investment growth and output growth have a dual causal relationship, and the relational signs reflect the results found in the estimation of Canadian data. Both the Canadian and American data indicate that public investment growth, while having a positive causal relation on output growth, faces a negative reverse causal relationship with output growth – indicative of the counter cyclical nature of functional finance. A key question relates to whether it is the most efficient route to generating growth. This apparent counter-cyclical nature of public investment growth in Canada and USA is the fulcrum of the concluding discussion section.

Empirical Summary

Overall this exercise could not decisively identify whether public investment acts as a short-run complement to other factor inputs in the Canadian context. However, various combinations of these factors test positive for cointegration relationships, indicating that long-run relationships exist among these variables. When this short-run analysis was extended to provincial and international cases, similarly ambiguous results were found. However, in terms of trends in Canada's public investment growth, it appears as though it has increased in times of economic downturn, while it has fallen in times of economic prosperity – indicating a policy preference of functional finance. This will be the main discussion point in the proceeding conclusion.

I now conclude this empirical section by quickly outlining certain shortcomings of this exercise and possibilities for further research. One sure reason for the lacklustre results in this paper is due to the short-run nature of this analysis. The adjustment process of private investment from productive shocks to public investment is likely to be captured in analyses that focus on long-run relationships, such as the Johansen cointegration technique, among others. But while there was very little evidence of any short-run causation, the Johansen cointegration test indicates long-run relationships in Canadian data. Also, refined national accounting principles could be of use in this exercise, as they are often cited as an impediment in measuring the impacts of different types of public activities and spending. Also the fact that the Akaike Information Criterion was used could have some impact on the optimal lag length, although in most cases other information criteria indicated optimal lags within one period of the AIC-determined length. This being said, a lot of useful information can be discussed here.

Concluding Discussion and Remarks:

The fact that public investment growth in Canada and the United States follows counter to output growth signifies that as output growth falls, it causes an upsurge in public investment growth (i.e., functional finance). Conversely, public investment growth has a positive impact on output growth. This counter-cyclical property of public investment reflects the policy rationale of the recent stimulus package in that output growth dropped and fiscal policies correspondingly grew. However the stimulus package was argued both through short-run employment factors and long-run productivity-enhancing factors. Despite no results of complementary relations between public investment and employment in Canadian data from 1962 to 2012, the reality is that the public infrastructure shocks of the stimulus package immediately helped local employment and income levels during the short run of severe economic crisis. However the deeper impacts of such infrastructure should be realized in improved productive capacity that can be utilized in the future.

Canada's stimulus package, particularly its infrastructure components, can be analyzed through two lenses – one for short-run impacts and one for long-run impacts. Given the economic environment at the time, more specifically a time of under-employment, many of these projects' most immediate "overnight" impacts were on employment. Because the economy was operating well under full capacity, these projects crowded in employment both directly and indirectly through increased employment from the projects and the resulting higher incomes. Conversely in the long run, the direct impacts of these projects on employment is minimal, and the productive nature of these infrastructure improvements will (hopefully) be reflected in increases in private investment, employment, and other factors.

But when we look at the diversity of the recent projects undertaken, it is clear that there were diverse programs undertaken. At one extreme, we have community based projects, such as the 474 projects that were completed by the National Trail Coalition to build and renew recreational trails across Canada. Other examples include the community centre renewal for Sayabec, QC and Langford, B.C.'s new hockey arena.

Many of these projects, while generating immediate employment through their commencement and completion, are difficult to argue through the lens of generating productive capacity in the long run. While the quality of life of residents will be improved with many of these projects, the long-run effect of these investments might very well be nil.

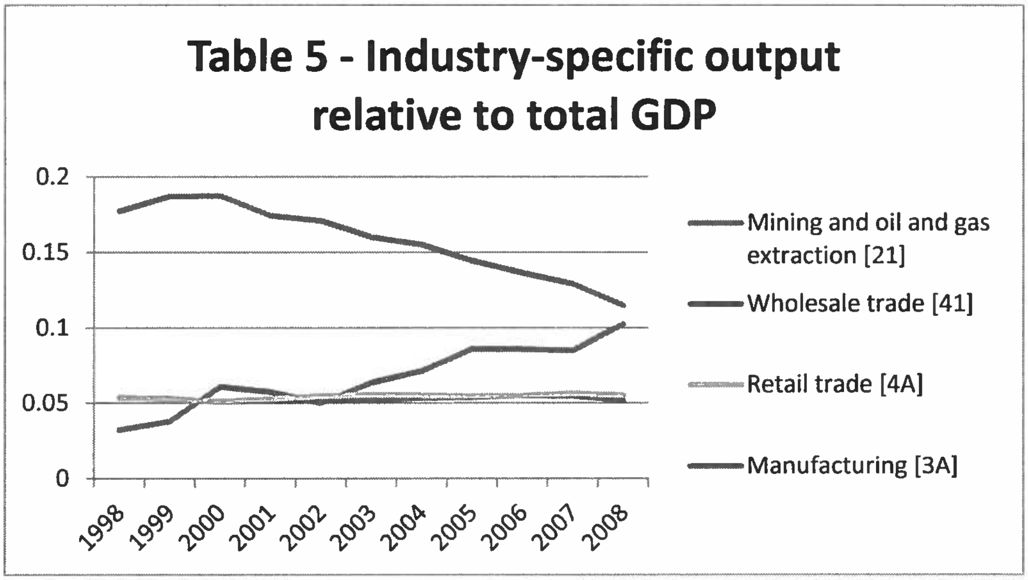
But there are also a number of projects that are intrinsically more related to longer-run capacity growth. As briefly mentioned, Alberta's Central Peace Region had two key roadways developed, which helped to sustain immediate employment through the crisis years. Furthermore, it was noted that it has "improved access to the industrial and agricultural network to enhance the flow of goods crucial to the regional economy." (Flaherty, March 2012). Other projects that can generate prolonged productive capacity include the improved wastewater system in Arichat, NS, and the new water treatment facility in Lorette, MB. Such projects not only serve the immediate purpose of increasing employment, but also have more opportunities of generating complementary crowding-in of other factors in the long-run. Specifically for the Alberta case, it is clear that such investments have generated new opportunities for future growth in certain industries – namely for mining and oil exploration. However, as was covered in the literature review, not all industries are equally affected by such public investments. The industry-specific impacts of the fiscal package necessitate a review of Kaldor's growth laws, which differentiate unique industries and their relations to economic growth.

To review, Kaldor (1966) posited three laws relating to economic and productivity growth that were based on Verdoorn's original contributions. In these laws, the manufacturing sector is deemed to be the engine of growth for a national economy.

The third law, arguably the most influential, states that as manufacturing output grows, it diverts labour away from sectors facing decreasing returns to scale. Manufacturing sectors face static and dynamic influences that contribute to increasing returns to scale. Thus expansion of this particular sector (or more realistically any industry facing increasing returns) allows for widespread productivity growth across an economy's industries.

It is well known that over the last 20 years Canada`s energy sector has grown considerably with respect to other industries. Arguments concerning the Dutch disease and Canada`s changing focus from a diversified industrial makeup to one centred on natural resources have been well-documented. To demonstrate how economic focus has shifted towards natural resources, Table 5 presents the total production of 4 industries (manufacturing, mining, wholesale trade, and retail trade) relative to Canada's gross domestic output.

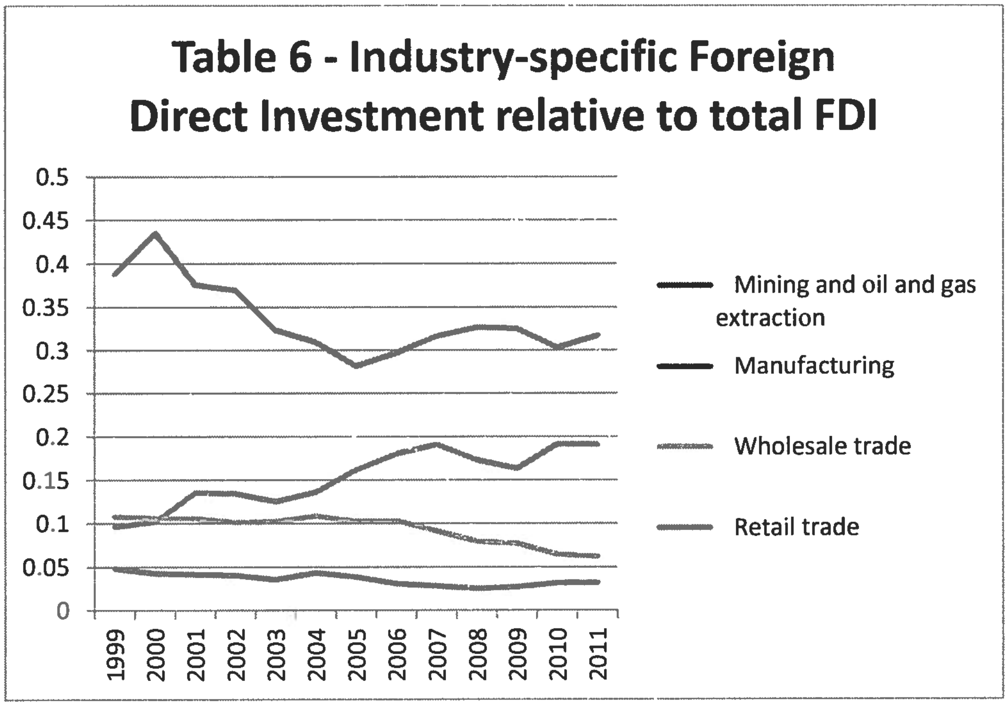
Over the course of these 20 years, mining and gas and oil exploration have grown considerably both in absolute terms and relative to gross output. The biggest changes appear to be the rise of relative oil and mining versus the drop in relative manufacturing. This is particularly stark given that this data is nationally aggregated, and mining expansion has been geographically isolated mainly in western provinces. In light of Verdoorn's and Kaldor's laws, unless new more efficient mining extraction techniques are being utilized, the expansion of this industry may not have the ability to take advantage of economies of scale and embodied technical change.



Statistics Canada. Table 379-0023 - Gross domestic product (GDP) at basic price in current dollars, System of National Accounts (SNA) benchmark values, by North American Industry Classification System (NAICS), annual (dollars), *CANSIM*, accessed July 26, 2012. N.B.: Wholesale trade and retail trade overlap around 0.05 (i.e. both lines are present)

In effect, manufacturing and similar sectors face greater opportunities to raise labour productivity growth. But despite the increase in generated relative output, it is equally important to track the investment decisions which have guided (and are guiding) the makeup of Canada's economic landscape. Table 6 presents a similar graph measuring Canada's industry-specific foreign direct investment (relative to total FDI). Mining and exploration are gradually taking on more foreign investments relative to other sectors.

Here we see that out of this sample, mining investment grew the most, nearly doubling its relative weight over this 13 year period. Conversely, the manufacturing sector slid from 0.435 in 2000 to 0.317 in 2011. It is apparent that focus of economic growth is being shifted towards natural resource exploration and extraction. Furthermore an intuitive reflection of Canada's stimulus indicates that the natural resource industry may be best suited to capitalize on the new public infrastructure investments.



Statistics Canada, Table 376-0052 Foreign Direct Investment Stocks in Canada, by North American Industry Classification System (NAICS), *CANSIM*, accessed July 26, 2012.

The decline of relative manufacturing output and its investment, and its apparent redirection to natural resource extraction, is a Canadian reality. Arguments surrounding Canada's infrastructure investments and their contributions to long-run economic growth must be framed through differentiated industrial lenses. Infrastructure projects have varying impacts across industries, with very little effect on manufacturing and other industries with greater potential for increasing-returns. If we disregard "community-centred" projects (such as rinks, sports facilities, leisure trails) which may increase the standards of living for local residents, we can look towards "productivity-enhancing" projects which can be argued to enhance economic capacity in the longer-run. However given changing compositional makeup of Canada's industrial output and investments, and the stimulus projects that have the ability to do so, the reality is that many of these productivity-enhancing projects are perhaps best suited for Canada's natural resource sector, which beyond the obvious environmental hazards is an industry with very little room to generate increasing returns and complementary spillovers to other sectors.

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Appendix 1: Hypothesis Sets (1) through (4)

Hypothesis Set (1):

(1_A): Public investment does not cause private investment (and its reverse)
(1_B): Public investment does not cause private non-residential structural investment ("...")
(1_C): Public investment does not cause private machinery and equipment investment ("...")
(1_D): Public investment does not cause employment ("...")
(1_E): Public investment does not cause hours worked ("...")
(1_F): Private investment does not cause employment ("...")
(1_G): Private investment does not cause hours worked ("...")
(1_H): Public investment does not cause output ("...")
(1_I): Private investment does not cause output ("...")
(1_J): Private non-residential structural investment does not cause output ("...")
(1_K): Private machinery and equipment investment does not cause output ("...")
(1_L): Public investment does not cause labour productivity (Y/H) ("...")
(1_M): Public investment does not cause labour productivity (Y/N) ("...")

Hypothesis Set (2):

(2_A): Provincial public investment does not cause provincial private investment (and its reverse)
(2_B): Provincial public investment does not cause provincial output ("...")

Hypothesis Set (3):

(3_A): International public investment does not cause private investment (and its reverse)
(3_B): International public investment does not cause output ("...")

Hypothesis Set (4):

(4_A): American total public investment does not cause private investment (and its reverse)
(4_B): American total public investment does not cause output (and its reverse)
(4_C): American federal public investment does not cause output (and its reverse)
(4_D): American state public investment does not cause output (and its reverse)

Appendix 2: Augmented Dickey-Fuller Tests (Canada, Annual Data, 1962-2011)

ADF Tests, Canada, Annual 1962-2011					
	Null Hypothesis: Time series contains a unit root				
	Level		1st Differences		Order of Integration
Variable	Akaike test statistic	Lag length	Akaike test statistic	Lag length	
ln(GGI)	-0.225342	0	-5.925808 (*)	1	I(1)
ln(PGI)	-4.247407 (*)	1	N/A	N/A	I(0)
ln(N)	-2.109747	1	-4.952695 (*)	0	I(1)
ln(H)	-4.382607 (*)	0	N/A	N/A	I(0)
(*) indicates significance at 1% level					
All tests were conducted with constant and time trend					

Appendix 3: Augmented Dickey-Fuller Tests (Provincial Data)

Variable	Null Hypothesis: Time series contains a unit root				
	Level		1st Differences		Order of Integration
	Akaike test statistic	Lag length	Akaike test statistic	Lag length	
ALBERTA					
ln(AB-GGI)	-1.385164	1	-5.068344 (*)	0	I(1)
ln(AB-PGI)	-3.020722	1	-4.460494 (*)	0	I(1)
ln(AB-Y)	-3.211715	1	-5.060487 (*)	0	I(1)
BRITISH COLUMBIA					
ln(BC-GGI)	-3.504537	6	-7.446125 (*)	0	I(1)
ln(BC-PGI)	-4.166178	0	-5.011957 (*)	0	I(1)
ln(BC-Y)	-2.622784	1	-2.392561	3	I(2)
MANITOBA					
ln(MB-GGI)	-1.087436	0	-4.728854 (*)	0	I(1)
ln(MB-PGI)	-2.863753	4	-3.19628 (***)	7	I(1)
ln(MB-Y)	-1.891676	7	-3.401676 (**)	6	I(1)
NEW BRUNSWICK					
ln(NB-GGI)	-3.097875	0	-5.654192 (*)	1	I(1)
ln(NB-PGI)	-4.329143 (*)	1	-4.136828	4	I(0)
ln(NB-Y)	-3.855026	6	-4.593819 (*)	0	I(1)
NEWFOUNDLAND					
ln(NL-GGI)	-2.103	3	-2.596	3	I(2)
ln(NL-PGI)	-3.539	2	-3.909 (**)	2	I(1)

ln(NL-Y)	-2.095	7	-2.645	5	I(2)
NOVA SCOTIA					
ln(NS-GGI)	-1.861	1	-5.703 (*)	0	I(1)
ln(NS-PGI)	-3.033	2	-4.041 (**)	0	I(1)
ln(NS-Y)	-4.021 (**)	6	-3.589	6	I(0)
ONTARIO					
ln(ON-GGI)	-1.934	0	-4.385 (*)	0	I(1)
ln(ON-PGI)	-5.612 (*)	2	-4.754	3	I(0)
ln(ON-Y)	-3.745 (**)	5	-3.023	5	I(0)
PRINCE EDWARD ISLAND					
ln(PEI-GGI)	-2.146	2	-7.333 (*)	1	I(1)
ln(PEI-PGI)	-4.241 (**)	1	-3.362	6	I(0)
ln(PEI-Y)	-1.293	6	-1.706	5	I(2)
QUEBEC					
ln(QC-GGI)	-1.306	0	-5.401 (*)	0	I(1)
ln(QC-PGI)	-4.232 (**)	4	-4.212	4	I(0)
ln(QC-Y)	-2.857	6	-3.402 (**)	6	I(1)
SASKATCHEWAN					
ln(SK-GGI)	-1.771	0	-3.896 (**)	5	I(1)
ln(SK-PGI)	-2.094	3	-2.824	7	I(2)
ln(SK-Y)	-4.421	1	-7.07 (*)	1	I(1)

(*) indicates 1% significance; (**) indicates 5% significance; (***) indicates 10% significance; All tests included a time trend and intercept

Appendix 4: Augmented Dickey-Fuller Tests (Canada, Quarterly Data, 1962-2011)

ADF Tests, Canada, Quarterly 1962-2011					
	Null Hypothesis: Time series contains a unit root				
	Level		1st Differences		
Variable	Akaike test statistic	Lag length	Akaike test statistic	Lag length	Order of Integration
ln(GGI)	-1.52134	2	-7.07124 (*)	1	I(1)
ln(GC)	-3.095	6	-3.776 (**)	5	I(1)
ln(PGI)	-3.32061	13	-4.46389 (*)	12	I(1)
ln(PNRS)	-2.906	4	-7.941 (*)	3	I(1)
ln(PME)	-4.057	3	-7.518 (*)	1	I(1)
ln(Y)	-2.05058	14	-4.30573 (*)	13	I(1)
(*) indicates significance at 1% level					
All tests were conducted with constant and time trend					

Appendix 5: Augmented Dickey-Fuller Tests (International Data)

Variable	Null Hypothesis: Time series contains a unit root				
	Level		1st Differences		Order of Integration
	Akaike test statistic	Lag length	Akaike test statistic	Lag length	
AUSTRALIA					
ln(AUS-GGI)	-1.39821	0	-4.44983 (*)	0	I(1)
ln(AUS-PGI)	-2.94541	1	-4.53172 (*)	5	I(1)
ln(AUS-Y)	-1.98416	0	-5.63692 (*)	0	I(1)
FRANCE					
ln(FRA-GGI)	-2.13878	4	-4.9053 (*)	0	I(1)
ln(FRA-PGI)	-3.72579 (**)	1	-3.5241 (***)	0	I(0)
ln(FRA-Y)	-2.13111	1	-2.88351	6	I(2)
NETHERLANDS					
ln(NET-GGI)	-1.4363	0	-6.31634 (*)	0	I(1)
ln(NET-PGI)	-3.20251	1	-4.40871 (*)	3	I(1)
ln(NET-Y)	-2.05756	1	-4.78917 (*)	0	I(1)
GERMANY					
ln(GER-GGI)	-3.18922	2	-4.1575 (*)	4	I(1)
ln(GER-PGI)	-3.20672	1	-3.71464 (**)	2	I(1)
ln(GER-Y)	-3.52185 (***)	1	-3.60244 (**)	4	I(2)
ITALY					
ln(ITA-GGI)	-3.0587	0	-7.11041 (*)	0	I(1)

ln(ITA-PGI)	-1.61009	0	-4.68853 (*)	0	I(1)
ln(ITA-Y)	0.097354	0	-4.31051 (*)	0	I(1)
KOREA					
ln(KOR-GGI)	-0.38707	0	-4.23256 (*)	0	I(1)
ln(KOR-PGI)	-1.45189	2	-5.42365 (*)	1	I(1)
ln(KOR-Y)	-0.11741	0	-6.06507 (*)	0	I(1)
FINLAND					
ln(FIN-GGI)	-3.05831	0	-6.11265 (*)	0	I(1)
ln(FIN-PGI)	-3.60465 (**)	1	-4.34435 (*)	3	I(1)
ln(FIN-Y)	-3.14694	1	-3.83401 (**)	0	I(1)
NEW ZEALAND					
ln(NZ-GGI)	-4.03626 (**)	3	-5.31325 (*)	0	I(1)
ln(NZ-PGI)	-2.7519	1	-2.55046	0	I(2)
ln(NZ-Y)	-2.57669	1	-2.5161	0	I(2)
UNITED KINGDOM					
ln(UK-GGI)	-5.945 (*)	0	N/A	N/A	I(0)
ln(UK-PGI)	-3.167	1	-8.358 (*)	1	I(1)
ln(UK-Y)	1.415	10	-4.674 (*)	2	I(1)

Appendix 6: Augmented Dickey-Fuller Tests (USA, Quarterly Data, 1947-2011)

ADF Tests, USA, 1947-2011					
	Null Hypothesis: Time series contains a unit root				
	Level		1st Differences		
Variable	Akaike test statistic	Lag length	Akaike test statistic	Lag length	Order of Integration
ln(GGI)	-0.910	15	-3.614 (**)	14	I(1)
ln(F-GGI)	-1.416	11	-6.388 (*)	11	I(1)
ln(S-GGI)	-1.614	4	-5.822 (*)	3	I(1)
ln(PGI)	-4.051 (*)	2	N/A	N/A	I(0)
ln(Y)	-1.704	1	-10.985 (*)	0	I(1)
(*) indicates significance at 1% level					
(*) indicates significance at 5% level					
All tests were conducted with constant and time trend					

Appendix 7 : Modified-Wald Tests - level and growth relationships between various factor inputs (Canada, 1962-2011)

Level Relationships (Canada, 1962-2011)							
Factor (A)	Factor (B)	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
Total public investment	Private fixed investment	2	3.200	0.202	1.919	0.383	No causality
Total public investment	Private non-residential structure investment	3	4.687	0.196	0.866	0.829	No causality
Total public investment	Private machinery & equip investment	4	1.497	0.827	2.092	0.719	No causality
Total public investment	Hours worked	2	0.401	0.818	1.824	0.402	No causality
Private fixed investment	Employment	2	1.326	0.515	4.232	0.121	No causality
Private fixed investment	Output	2	7.781	0.0204 (*)	6.627	0.0364 (*)	Dual
Private non-residential structure investment	Output	2	1.370	0.504	5.712	0.058 (*)	One way
Private machinery & equip investment	Output	4	10.974	0.0119 (*)	14.82	0.002 (*)	Dual
Total public investment	Output	3	1.934	0.586	6.767	0.080 (*)	One way
Total public investment	Labour productivity (Y/H)	2	0.894	0.640	0.483	0.785	No causality
Total public investment	Labour productivity (Y/N)	2	1.806	0.405	1.186	0.553	No causality

Growth Relationships (Canada, 1962-2011)							
Factor (A)	Factor (B)	Optimal Lag (AIC)	Null Hypotheses: (A) does not Granger Cause (B)		Null Hypotheses: (B) does not Granger Cause (A)		Causality
			χ^2	p-value	χ^2	p-value	
Total public investment	Private fixed investment	2	1.595285	0.4504	0.974106	0.6144	No causality
Total public investment	Private non-residential structure investment	4	4.313	0.365	5.454	0.244	No causality
Total public investment	Private machinery & equip investment	2	0.642	0.725	1.552	0.670	No causality
Total public investment	Employment	1	0.0084	0.927	1.367	0.245	No causality
Total public investment	Hours worked	2	0.883	0.347	0.05	0.823	No causality
Private fixed investment	Employment	1	0.0935	0.76	1.067	0.302	No causality
Private fixed investment	Hours worked	2	1.60	0.550	6.114	0.041 (*)	One way
Private fixed investment	Output	1	9.393962	0.0022 (*)	11.30783	0.0008 (*)	Dual
Private non-residential structure investment	Output	4	8.144	0.0864 (*)	14.798	0.0051 (*)	Dual
Private machinery & equip investment	Output	1	9.614	0.0119 (*)	12.216	0.0005 (*)	Dual
Total public investment	Output	1	2.734	0.0982 (*)	4.60314	0.0319 (*)	Dual
Total public expenditures	Output	6	18.430	0.0052 (*)	15.766	0.0273 (*)	Dual
Total public investment	Labour productivity (Y/H)	1	1.838	0.175	0.744	0.785	No causality
Total public investment	Labour productivity (Y/N)	0	N/A	N/A	N/A	N/A	N/A

Appendix 8: Johansen cointegration tests for long-run relationships in Canadian annual data (1962-2011)

Variables included	Max # Hypothesized C.E.`s	Eigenvalue	Trace Statistic	0.05 Critical value	p-value	# C.E.`s @ 5%
Y, GI, PI	0	0.442308	47.03479	42.91525	0.0183 (*)	1
	1	0.256647	21.34105	25.87211	0.1654	
	2	0.171749	8.291328	12.51798	0.2288	
Y, GI, PI, H	0	0.800631	122.5219	63.8761	0 (*)	2
	1	0.45588	51.56761	42.91525	0.0055 (*)	
	2	0.285446	24.78983	25.87211	0.0677	
	3	0.203325	10.00157	12.51798	0.1271	
Y, GI, PI, N	0	0.745986	111.5391	63.8761	0 (*)	2
	1	0.5181	51.24295	42.91525	0.006 (*)	
	2	0.251664	19.12217	25.87211	0.2736	
	3	0.134711	6.366441	12.51798	0.4152	
Y, GI, PI, H, GC	0	0.830753	200.7883	88.8038	0 (*)	4
	1	0.682071	122.6269	63.8761	0 (*)	
	2	0.58444	72.20609	42.91525	0 (*)	
	3	0.394033	33.56843	25.87211	0.0045 (*)	
	4	0.23048	11.52751	12.51798	0.0728	
Y, GI, PI, N, GC	0	0.864139	243.6686	88.8038	0 (*)	5
	1	0.763501	155.8393	63.8761	0 (*)	
	2	0.612811	92.3996	42.91525	0 (*)	
	3	0.532581	50.65056	25.87211	0 (*)	
	4	0.323362	17.18725	12.51798	0.0077 (*)	
Y/N, GI, PI	0	0.415045	42.55521	42.91525	0.0543	0
	1	0.28351	18.96151	25.87211	0.2831	
	2	0.092945	4.292303	12.51798	0.6995	
Y/H, GI, PI	0	0.389398	41.05918	42.91525	0.0758	0
	1	0.237093	19.35354	25.87211	0.2604	
	2	0.155689	7.446301	12.51798	0.3003	
Y/N, GI, PI, N	0	0.745986	111.5391	63.8761	0 (*)	2
	1	0.5181	51.24295	42.91525	0.006 (*)	
	2	0.251664	19.12217	25.87211	0.2736	
Y/H, GI, PI, H	0	0.800631	122.5219	63.8761	0 (*)	2
	1	0.45588	51.56761	42.91525	0.0055 (*)	
	2	0.285446	24.78983	25.87211	0.0677	
Y/H, GI, PI, H, GC	0	0.830753	200.7883	88.8038	0 (*)	4
	1	0.682071	122.6269	63.8761	0 (*)	
	2	0.58444	72.20609	42.91525	0 (*)	

		3	0.394033	33.56843	25.87211	0.0045 (*)	
		4	0.23048	11.52751	12.51798	0.0728	
Y/N, GI, PI, H, GC		0	0.842723	227.5406	88.8038	0 (*)	4
		1	0.74497	146.1518	63.8761	0 (*)	
		2	0.601968	86.03129	42.91525	0 (*)	
		3	0.555967	45.49744	25.87211	0.0001 (*)	
		4	0.199225	9.775722	12.51798	0.1377	

Appendix 9: Modified-Wald Tests - level and growth relationships between public and private fixed capital investments (Provinces, 1981-2011)

Level Relationships between Investment Inputs (Provinces, 1981-2011)							
			Null Hypotheses				Causality
(A): Total public investment	(B): Private fixed investment	Optimal Lag (AIC)	(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
ALBERTA		1	1.4617	0.226	0.01805	0.893	No causality
BRITISH COLUMBIA		1	0.1872	0.6652	0.0147	0.903	No Causality
MANITOBA		2	0.615	0.7352	1.816	0.403	No causality
NEW BRUNSWICK		3	3.418	0.331	3.436	0.329	No causality
NEWFOUNDLAND		1	0.4235	0.5152	1.3001	0.2542	No causality
NOVA SCOTIA		3	6.480	0.0904 (*)	0.0650	0.7987	One way
ONTARIO		2	5.162706	0.1603	6.62305	0.0365 (*)	One way
PEI		1	0.0514	0.816	0.061355	0.8044	No Causality
QUEBEC		1	0.643932	0.4223	0.08676	0.7683	No causality
SASKATCHEWAN		1	0.009397	0.9228	0.117166	0.7321	No causality

Growth Relationships between Investment Inputs (Provinces, 1981-2011)							
			Null Hypotheses				Causality
(A): Total public investment	(B): Private fixed investment	Optimal Lag (AIC)	(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
ALBERTA		1	0.331	0.565	0.194	0.659	No causality
BRITISH COLUMBIA		1	0.233	0.629	0.0991	0.753	No Causality
MANITOBA		1	0.004	0.950	1.131	0.287	No causality
NEW BRUNSWICK		1	1.237	0.266	1.573	0.2097	No causality
NEWFOUNDLAND		1	0.1357	0.713	0.300	0.584	No causality
NOVA SCOTIA		1	0.748	0.387	0.0788	0.779	No causality
ONTARIO		1	0.0492	0.825	7.995	0.006 (*)	One way
PEI		1	0.0836	0.772	0.981	0.322	No Causality
QUEBEC		1	0.584	0.445	2.630	0.105	No causality
SASKATCHEWAN		1	0.229	0.632	0.377	0.594	No causality

Appendix 9 continued : Modified-Wald Tests - level and growth relationships between public investments and output (Provinces, 1981-2011)

Level Relationships between Public investment and Output (Provinces, 1981-2011)							
(A): Total public investment	(B): Total output	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
ALBERTA		1	1.203	0.273	1.788	0.181	No causality
BRITISH COLUMBIA		1	0.0012	0.972	0.316	0.574	No causality
MANITOBA		1	0.506	0.477	0.333	0.564	No causality
NEW BRUNSWICK		1	2.906	0.088 (*)(-0.05)	0.079	0.776	One way
NEWFOUNDLAND		2	0.789	0.674	3.435	0.180	No causality
NOVA SCOTIA		2	7.374	0.0250 (*)(-0.06)	0.0839	0.959	One way
ONTARIO		2	2.644	0.267	1.829	0.401	No causality
PEI		4	12.424	0.0145 (*)	15.253	0.0042 (*)	Dual
QUEBEC		3	2.473	0.480	5.174	0.160	No causality
SASKATCHEWAN		4	14.637	0.0055 (*)(---)	7.565	0.109	One way

Level Relationships between Public investment and Output (Provinces, 1981-2011)							
(A): Total public investment	(B): Total output	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
ALBERTA		0	N/A	N/A	N/A	N/A	N/A
BRITISH COLUMBIA		1	N/A	N/A	N/A	N/A	N/A
MANITOBA		0	N/A	N/A	N/A	N/A	N/A
NEW BRUNSWICK		0	N/A	N/A	N/A	N/A	N/A
NEWFOUNDLAND		1	N/A	N/A	N/A	N/A	N/A
NOVA SCOTIA		2	7.457	0.024 (*)	0.570	0.752	One way
ONTARIO		2	4.744	0.0933 (*)	1.012	0.603	One way
PEI		3	2.750	0.431	16.338	0.001 (*)	One way
QUEBEC		2	0.596	0.742	0.478	0.788	No causality
SASKATCHEWAN		3	3.002	0.391	13.957	0.003 (*)	One way

Appendix 10 : International comparisons of public/private investment relationships

Level Relationships between Investment Inputs							
(A): Total public investment	(B): Private fixed investment (excluding residential structures)	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
AUSTRALIA		4	1.495	0.201	17.61	0.01 (*)	One way
FINLAND		2	2.155	0.340	11.717	0.20	No causality
NETHERLANDS		1	0.024	0.878	2.572	0.109	No causality
FRANCE		2	2.098	0.350	4.161	0.09 (*)	One way
GERMANY		3	8.124	0.0435 (*)	1.052	0.789	One way
ITALY		2	2.927	0.232	6.820	0.33	No causality
KOREA		1	0.006	0.939	9.163	0.0025 (*)	One way
NEW ZEALAND		2	1.138	0.554	18.28	0.01 (*)	One way
UNITED KINGDOM		3	1.484	0.223	0.239	0.625	No causality
USA		5	1.063	0.957	6.183	0.2889	No Causality

Growth Relationships between Investment Inputs							
(A): Total public investment	(B): Private fixed investment (excluding residential structures)	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
AUSTRALIA		1	0.543	0.761	0.468	0.494	No causality
FINLAND		4	5.942	0.204	11.116	0.029 (*)	One way
NETHERLANDS		1	0.108	0.743	0.412	0.521	No causality
FRANCE		1	0.764	0.388	5.760	0.020 (*)	One way
GERMANY		3	5.096	0.165	3.236	0.357	No causality
ITALY		1	4.04	0.044 (*)	4.003	0.045 (*)	Dual
KOREA		2	2.385	0.304	2.632	0.268	No causality
NEW ZEALAND		2	0.515	0.773	20.37	0.001 (*)	One way
UNITED KINGDOM		2	0.354	0.838	1.062	0.588	No causality
USA		4	1.534	0.8206	3.660	0.4540	No causality

Appendix 10 continued: International comparisons of public/private investment relationships

Level Relationships between Public investment and Output							
(A): Total public investment	(B): Output	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
AUSTRALIA		4	0.437	0.5084	0.0157	0.901	No causality
FINLAND		2	1.373	0.503	10.789	0.01 (*)	One way
NETHERLANDS		3	0.019	0.99	18.96	0.003 (*)	One way
FRANCE		2	2.250	0.323	3.973	0.137	No causality
GERMANY		3	1.912	0.591	8.989	0.029 (*)	One way
ITALY		1	0.682	0.409	2.215	0.137	No causality
KOREA		1	0.380	0.538	3.027	0.082 (*)	One way
NEW ZEALAND		1	N/A	N/A	N/A	N/A	N/A
UNITED KINGDOM		2	3.051	0.2175	5.409	0.068 (*)	One way
USA		6	12.577	0.050 (*)	8.372	0.212	One way

Growth Relationships between Public investment and Output							
(A): Total public investment	(B): Output	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
AUSTRALIA		1	0.907	0.341	0.095	0.758	No causality
FINLAND		1	0.019	0.892	1.121	0.289	No causality
NETHERLANDS		2	0.162	0.99	18.99	0.001 (*)	One way
FRANCE		1	N/A	N/A	N/A	N/A	N/A
GERMANY		3	16.6	0.001 (*)	0.455	0.929	One way
ITALY		0	N/A	N/A	N/A	N/A	N/A
KOREA		0	N/A	N/A	N/A	N/A	N/A
NEW ZEALAND		2	1.637	0.441	15.07	0.001 (*)	One way
UNITED KINGDOM		1	2.582	0.108	2.657	0.103	No causality
USA		5	9.170	0.0570 (*)	4.883	0.2995	One way

Appendix 11 : Refined look at USA quarterly data (1947-2011)

Level Relationships (USA, 1947-2011)							
Factor (A)	Factor (B)	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
Total public investment	Private fixed investment	5	1.063	0.957	6.183	0.2889	No Causality
Total public investment	Output	6	12.577	0.050 (*)	8.372	0.212	One way
Federal public investment	Output	5	6.112	0.295	8.318	0.140	No causality
State Public investment	Output	6	26.726	0.002 (*)	16.349	0.012 (*)	Dual

Growth Relationships using Quarterly Data (USA, 1947-2011)							
Factor (A)	Factor (B)	Optimal Lag (AIC)	Null Hypotheses				Causality
			(A) does not Granger Cause (B)		(B) does not Granger Cause (A)		
			χ^2	p-value	χ^2	p-value	
Total public investment	Private fixed investment	4	1.534	0.8206	3.660	0.4540	No causality
Total public investment	Output	5	9.170	0.0570 (*)	4.883	0.2995	One way
Federal public investment	Output	8	10.828	0.2117	32.924	0.001 (*)	One way
State Public investment	Output	5	20.879	0.009 (*)	14.056	0.015 (*)	Dual