

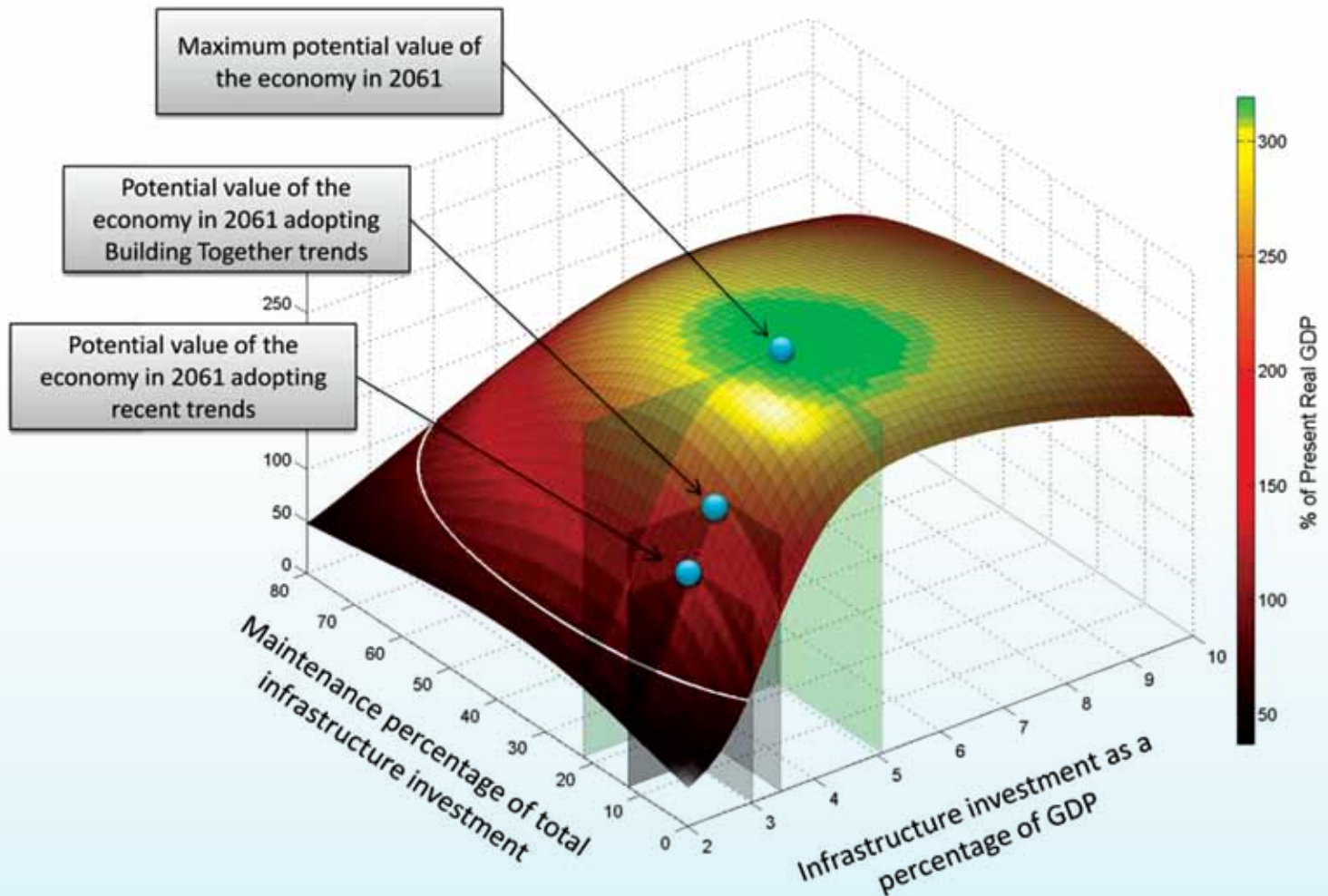


RESIDENTIAL AND  
CIVIL  
CONSTRUCTION  
ALLIANCE OF  
ONTARIO

An Independent Study Commissioned by

**RCCAO**

**Constructing Ontario's Future**



## Public Infrastructure Investment in Ontario:

### The Importance of Staying the Course


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## **The Importance of Staying the Course**

December 2011

An Independent Study Commissioned by the  
The Residential and Civil Construction Alliance of Ontario



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## **Preface**

This research was undertaken by RiskAnalytica for The Residential and Civil Construction Alliance of Ontario. In keeping with RiskAnalytica's guidelines for financed research, the design and method of research, as well as the content of this study, were determined solely by the authors. The research was conducted by David Stiff, Paul Smetanin, and Douglas McNeil.

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Forecasts and research often involve numerous assumptions and data sources, and are subject to inherent risks and uncertainties. This information is not intended as specific investment, accounting, legal, or tax advice.

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## Executive Summary

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### Preface

The Ontario government recently announced a 10-year infrastructure plan titled *Building Together*. It promises to build upon the long-term approach to infrastructure investment from the previous *ReNew Ontario* plan. As a result, the awareness of infrastructure investment in Ontario has increased. However, while the public has an intuitive understanding of the importance of infrastructure to the economic prosperity of the province, it is likely that the majority of the population does not fully recognize the personal risks associated with continued underinvestment.

This study looked to quantify the risks for individuals, business, and the government associated with infrastructure underinvestment and examined the progress made so far in mitigating these risks. The recent and proposed increases in infrastructure investment from the *ReNew Ontario* and *Building Together* plans are an important step in the right direction, but greater macroeconomic benefits can be realized with further infrastructure investment with a stronger focus on maintaining existing infrastructure.

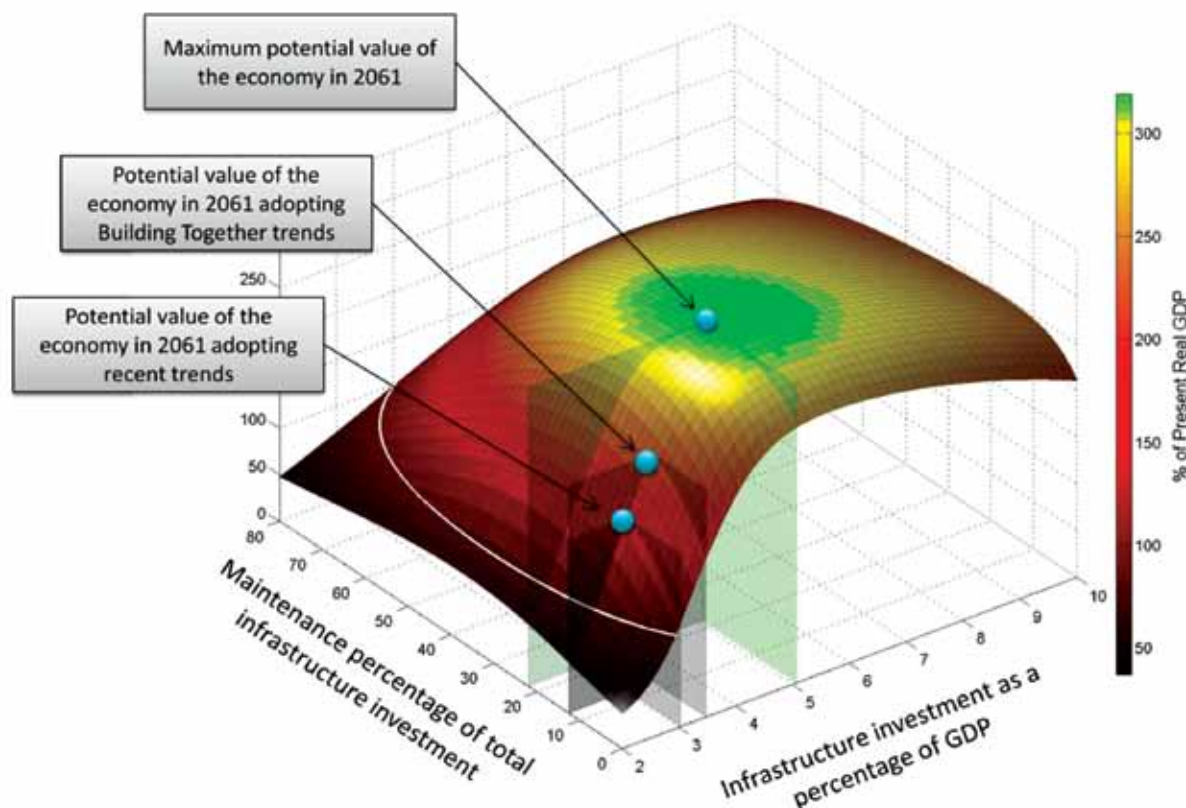
Over the next 50 years, there is a risk of public infrastructure underinvestment in Ontario that could cost the provincial economy over 1% annual growth in real gross domestic product (GDP). For individual workers, depending upon the number of years they plan on staying in the labour force, it could cost them between \$20,000 and \$60,000 in today's dollars. Businesses also face the loss of an annual 0.7% increase in profits.

Quantifying the relationship between public infrastructure and economic prosperity is a challenging and complex task: there is limited information on these points. The research relies on mathematical modelling of demographics, labour force, production, taxation, and wages to estimate the long-term connections between public infrastructure investment – both on new infrastructure and on maintenance – and economic production, real after-tax wages, and real net profits after-tax. The results of this analysis are not intended to dictate public infrastructure investment policy in Ontario, but rather to emphasize the potential economic risk that Ontario's employees and employers bear when long-term infrastructure trends tend towards persistent underinvestment.

### Results at a Glance

**Moving in the right direction:** Recent increases in Ontario's level of infrastructure investment have the potential to increase average annual real GDP growth by over 1% as compared to previous historical trends. By maintaining the estimated infrastructure investment levels proposed in Ontario's **Building Together** 10-year infrastructure plan over the long term, an additional 0.6% annual real growth could potentially be realized. In line with increased GDP growth, wages and employment, corporate profits, and government revenue also all increase.

**Societal risk of lost opportunity:** A graphical representation of the connection between infrastructure investment policies and economic growth illuminates the societal risk of poor infrastructure policies by showing the relationship between total public infrastructure investment as a percentage of GDP, maintenance investment, and the 2060 real value of GDP as a percent of 2009 GDP (vertical axis).



The 3D visualization of the results clearly illustrates that an adequately funded, stable, long-term infrastructure policy secures the foundation of long-term economic production (the plateau). It is evident that the adoption of the recent trend of about 3% of GDP for the next 50 years puts this foundation on a risky slope, in a place where reductions in infrastructure investment or misallocations could have a disproportionate impact upon the deterioration of economic growth. Ontario's 10-year **Building Together** plan moves the situation up the slope in the right direction but remains in a precarious position where small decreases in infrastructure funding can significantly impact economic growth. The target policy, which yields the maximum potential economic growth, increases infrastructure investment to 5% of GDP, of which 22% is spent on infrastructure maintenance.

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**Personal risk of lost opportunity:** Employees are one of the key stakeholders in public infrastructure. Sufficient infrastructure helps to improve productivity, resulting in greater wages and employment. Relative to maintaining recent historical trends, a 0.9% average annual growth in total after-tax wages is at risk if infrastructure investment does not move towards the target policy. In addition, over the next 50 years, more than 12 million person-years of employment are at risk. For an individual entering the labour force today, that is the equivalent of over \$425,000 in real 2010 dollars (or \$60,000 in today's present value terms) by the time they reach age 65.

**Business risk of lost opportunity:** Employers are also not immune to the risks of long-term underinvestment in public infrastructure. For companies with long-term plans in Ontario, after 50 years, an average of 29% of their net profit after tax is at risk due to insufficient public infrastructure. From a different point of view, an average annual real growth of 0.7% in net profit after taxes is at risk.

**Infrastructure investment can be cost-effective:** Infrastructure should be viewed as an investment rather than an expense. While it does cost money to build and maintain, it acts to boost productivity and growth resulting in significant returns. In the case of an individual employee, for every additional dollar paid in income tax as policies are changed from the recent trends to the target policy over a 50 year timeframe, an additional \$1.90 in real after-tax wage is realized. From the government perspective, the present value of the additional cumulative government revenue over the next 50 years is 342% of the present value of the required additional investments to move from the recent trends of 3% of GDP invested in infrastructure to the target policy of 5%.

**Stable investment is better than volatile spending:** The benefits of increased infrastructure investment stated above assume a predictable and stable infrastructure investment strategy over a 50 year period. Historically, this type of behaviour has not been observed over such long time frames. However, the stability is crucial for maximizing the economic benefits of the investment. Even in a situation where the long-term average level of infrastructure investment is maintained, the annual volatility acts to reduce the positive benefits of infrastructure investment.

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## Conclusions

Over the past decade, the level of infrastructure investment in Ontario has been moving in the right direction, thereby increasing the potential growth of the economy. Ontario's 10-year **Building Together** infrastructure plan is a further step toward increasing the economic potential of the province. However, there is still additional room for further infrastructure investment from the current levels of 3% of provincial GDP to up to 5% of provincial GDP before the marginal returns disappear. In parallel with increasing the level of overall infrastructure investment, the percent allocated to the maintenance of existing infrastructure should be increased significantly, by up to 22% of total infrastructure investment. Ontario has historically spent only 12% of total infrastructure investment on maintenance, well below the Canadian average. Relative to the recent trend in infrastructure investment, the increase in infrastructure investment and maintenance could:

- Increase after-tax wages by almost 60%, with those entering the work force today having the equivalent of more than \$400,000 real wages earned by age 65;
- Increase net profits after tax by almost 30%, equivalent to a 0.7% annual increase;
- Increase employment by over 12 million person-years; and
- Result in an additional \$7 trillion in cumulative government revenue while costing only \$1.5 trillion (over the 50 years)

The general conclusions are robust to changes in the estimated elasticity of production for public capital. While the exact numerical values change, the conclusion that current levels of infrastructure investment and maintenance are well below the levels for maximum macroeconomic growth remain unchanged.

Given the importance of public infrastructure to the future economic prosperity of Ontario, it is critical that stable and predictable infrastructure investment is at least maintained, if not increased considerably. In addition, further research should be conducted into the benefits of specific classes of infrastructure to determine which type of infrastructure has the greatest economic impact. This type of analysis would assist in prioritizing various infrastructure projects from a macroeconomic point of view.

## 1.0 Introduction

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Public infrastructure plays a vital role in ensuring continued economic prosperity. Throughout the 1960s in Ontario, significant investments in infrastructure were made. However, investment levels in infrastructure fell considerably from the mid-1970s through to 2000, resulting in a decline in both the quantity and quality of infrastructure in Ontario (1). This period of low investment has led to an estimated national infrastructure deficit of over \$123 billion (2007 estimate) (2). In addition, the lack of sufficient public infrastructure also directly impacts economic productivity. For example, an Organisation for Economic Co-operation and Development (OECD) study estimates that insufficient transportation infrastructure costs Toronto \$3.3 billion dollars annually due to traffic congestion (3).

The importance of improving Ontario's infrastructure has been recognized by both the public and the government. A survey by the Federation of Canadian Municipalities (FCM) indicates that 96% of Canadians would like government to maintain or increase infrastructure investment (4). Infrastructure ranked second only to health care in terms of items to protect from investment cuts.

The Ontario government has also acted to improve public infrastructure over the last decade. In 2005, the Ontario government announced its ReNew Ontario infrastructure plan—an initial five-year plan to start the process of restoring and expanding Ontario's public infrastructure. To aid in the planning, funding, and managing of large infrastructure projects, the Ontario government created Infrastructure Ontario. From 2005 to 2009, infrastructure investment almost doubled from \$6.6 billion to \$12 billion. The ReNew Ontario plan has been followed with the 10-year *Building Together: Jobs and Prosperity for Ontarians* (1) infrastructure plan announced in 2011. Initial funding announcements for the *Building Together* plan promise \$35 billion in new infrastructure investment over the next three years.

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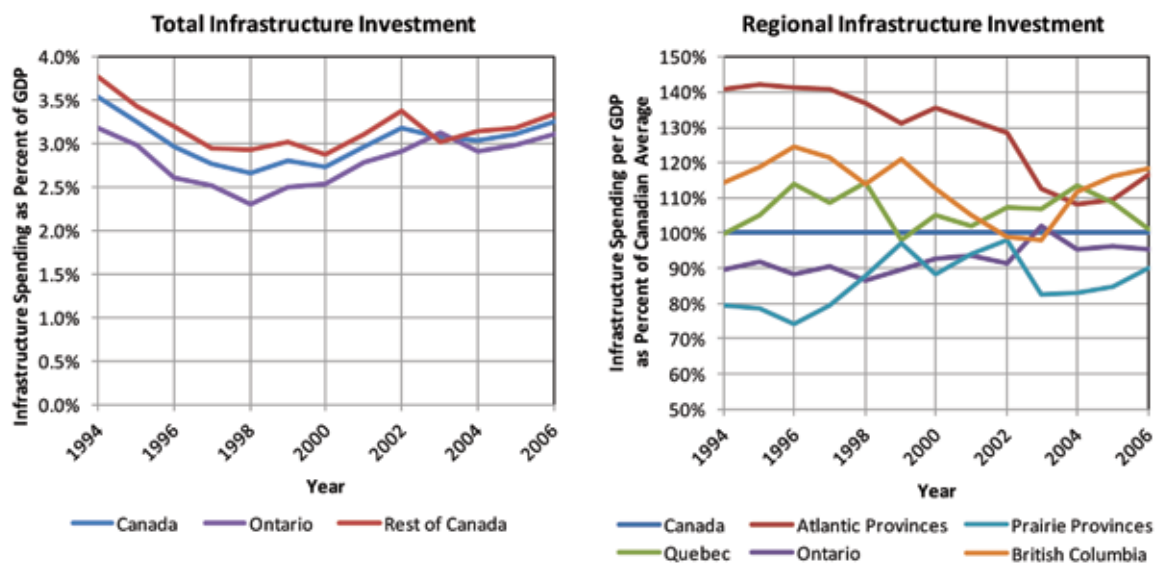
The recent investments and the long-term approach to infrastructure planning by the Ontario government is a step in the right direction. A study by the Conference Board of Canada indicated that every dollar invested in infrastructure in Ontario created about \$1.11 in economic growth (5). Numerous other studies have also supported the connection between infrastructure and GDP growth both internationally (6; 7; 8) and in Canada (9; 10; 5). The questions that then arise are, what are the long-term implications of the recent changes in infrastructure investment policies? And, what should the target level of infrastructure investment be such that economic prosperity is maximized? A previous analysis examined this question for Canada as a whole (11) and this report extends that study to focus on Ontario.

As in the national analysis, this study aims to emphasize the importance of long-term public capital management in terms with which stakeholders can readily identify, leading to an understanding of the risks associated with infrastructure policies. For long-term prosperity, there is a need for an appropriate balance between investment in new infrastructure and the maintenance of existing infrastructure. Following this line of inquiry, the study considers the sensitivity of future wages and employment, corporate profits, government revenue, and GDP to total infrastructure investment and the balance between new investment and maintenance.

The results are not intended to be a definitive statement as to what public infrastructure investment policy should be in Ontario. Rather, the results endeavour to emphasise the potential economic risk that Ontario's employees, employers, and the government bear when long-term infrastructure planning is in jeopardy.

## 1.1 Infrastructure Investment in Ontario

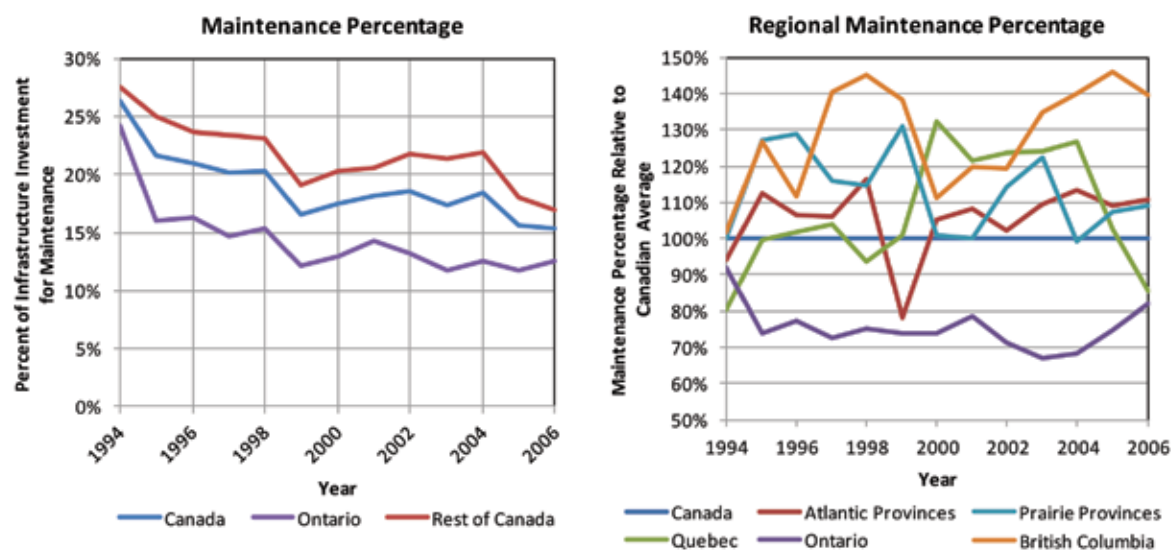
Investment in infrastructure in Ontario has varied considerably over the years. As the economy grows, the dollar value of infrastructure investment tends to increase as well. In order to standardize the level of infrastructure investment over long timeframes, this report measures infrastructure in terms of the percentage of GDP. Figure 1 shows how investment levels in infrastructure from all levels of government in Ontario have been significantly below that of most regions in Canada over the past 15 years. While recent trends have closed the gap between the various regions of Canada, in 2006 only the prairie provinces (Alberta, Saskatchewan, and Manitoba) had lower infrastructure investment when measured as a percentage of their GDP.



**Figure 1:** Total infrastructure spending as a percent of GDP from 1994 to 2006 for Ontario, Canada, and other regions in Canada.

Studies have estimated returns on infrastructure investment in Canada have ranged from a low of 11% to a high of 25%, with several other studies falling within this range (12; 13; 14; 15). In contrast, the return on private capital is around 10% to 13% (13; 15). In an economy with an appropriate balance of private and public capital (infrastructure), one would expect that the return on private investment would be greater than the return on public investments. This finding implies that there has been a long-term shortage of Canadian public infrastructure investment (12). As levels in infrastructure investment in Ontario have historically been below the Canadian average, as measured as a percentage of GDP, the ratio of private to public capital is likely even further out of balance. In addition, the lower levels of infrastructure investment imply that significant returns on additional infrastructure investment are available.

Equally important as the overall level of infrastructure investment is the way in which the investment is split between the creation of new infrastructure and the maintenance of existing infrastructure. If infrastructure is not maintained, it will decay faster than properly maintained capital, resulting in less effective contributions to production. In addition, the longer maintenance is delayed, the greater the cost of restoring the infrastructure to its full productive value. In contrast, focusing too heavily on maintaining existing infrastructure may result in insufficient new infrastructure to support a growing population and economy. Therefore, an appropriate balance between the creation of new infrastructure and the maintenance of existing infrastructure must be achieved. Figure 2 shows the recent trends in maintenance levels from 1994 to 2006. In Canada overall, the percent of infrastructure spending being used for maintenance has been decreasing. Most striking, however, is the significant difference between levels of maintenance spending in Ontario compared to the rest of the country. Maintenance levels in Ontario were almost 20% below the national average in 2006 and have at times been more than 30% below national levels.



**Figure 2:** Percent of total infrastructure investment spent on repair and maintenance in Ontario, Canada and relative to the Canadian average.

It should be noted that the definition of what constitutes public infrastructure is not without controversy. As the focus is on a macroeconomic analysis, and in order to be consistent with other Canadian macroeconomic studies such as those by Macdonald (15), the definition of public infrastructure adopted for this project corresponds to the Statistics Canada definitions where capital and investment is decomposed into business sector and public sector contributions.

## 1.2 The Importance of a Long-term Infrastructure Planning Approach to Maximize Economic Growth

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There is increasing recognition that successful infrastructure planning requires a long-term approach. Ontario's 10-year *Building Together* plan, in conjunction with the creation of Infrastructure Ontario to provide and generate expertise in asset management, show recognition on the part of government that short-term plans for infrastructure do not work. In addition to governments taking the long-term view, private industry associations, such as the Association of Consulting Engineering Companies, also strongly support long-term infrastructure planning and asset management (16).

In order to reduce the infrastructure deficit, forward-looking, long-term solutions are required [see (17)]. Simply reducing the infrastructure deficit does not guarantee the best possible growth for the economy. In particular, infrastructure deficit estimates do not include the cost and maintenance of new infrastructure required for future demographic and economic expansion. Therefore, rather than focussing on elimination of the infrastructure deficit, an arguably more pertinent focus is one that investigates the long-term infrastructure policies that maximize economic growth in the future, starting with the current state of infrastructure today. This argument has been made several times in ReNew Canada, the infrastructure renewal magazine, including in "Bridging the [Funding] [Knowledge] [Data] Gap" (18).

There are several aspects to long-term planning. Successful infrastructure management relies upon both a commitment to investment and a full lifecycle analysis of the costs involved (i.e. 19 and documents therein). However, at the highest level, there are two main factors governing the growth of infrastructure:

- The total amount spent on infrastructure
- The fraction of investment directed towards the maintenance of existing infrastructure as opposed to new capital investments

The historical values for these two parameters are shown in Figure 1 and Figure 2. Of particular interest is the outcome of following the recent infrastructure policy trend where total infrastructure investment over the last decade in Ontario has averaged around 3%, and maintenance around 12% of total investment compared to the trends implied by the *Building Together* 10-year plan, and the trend which yields the greatest potential economic benefits.

## 1.3 Reframing the Infrastructure Investment Debate: Resonating With Ontarians

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Canadians implicitly recognize the importance of infrastructure to continued prosperity and a high quality of life (4). However, it is difficult to make a direct connection between macroeconomic costs and the benefits of infrastructure investment to individuals. Citing a municipal infrastructure deficit of \$123 billion sounds staggering but might not resonate on a personal level with community members. In general, when large numbers are used, we are at risk of becoming cognitively numb, with diminishing psychological sensitivity as numbers become increasingly large and more abstract (20). The effect is particularly pronounced when information is not framed in a context with which we are familiar (21). For example, the simple statement that poor infrastructure management would reduce real GDP in Ontario by almost one trillion dollars by 2061 may be difficult to comprehend by individual workers. Alternatively, advising employees that it might cost each of them the equivalent of \$50,000 today (as an example), or the equivalent of over \$400,000 by retirement, may result in a much stronger connection with the issue. In most situations, people are risk averse (22); if they feel personally at risk due to infrastructure decisions, they are more likely to become involved in the conversation. Therefore, it is important to relate macroeconomic conclusions to the individual stakeholders in a more meaningful way.

The primary stakeholders of infrastructure in Canada are individual employees, employers (for example, corporations), and society overall. To make the impact of infrastructure policy personal to each of these stakeholders, the primary outcomes of the model are after-tax wages, net profit after tax, and total GDP. The results of this analysis are put into terms that the Canadian public, employees, and employers can relate to.

In Section 3, we will demonstrate how a macroeconomic analysis can be translated directly into terms to which these primary stakeholders can relate.

## 2.0 A 50-Year Approach to Modelling Infrastructure Policies

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In order to capture and analyze the economic impacts of infrastructure policy for all stakeholders, a model must include the direct effects of infrastructure upon production and the extent to which the labour force, government revenues, and corporate profits are affected. In addition, since infrastructure management is a long-term endeavour, the study investigates the effects of infrastructure policies on the Canadian economy over the next 50 years until 2061. The model is the same as the one that was used for the Canadian analysis (11) but with Ontario-specific data inputs. An overview of the model is provided in the following section. A detailed technical methodology is provided in Appendix C.

### 2.1 Overview of Modelling Infrastructure Policy Impacts in Ontario

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There are two key model components required to study the long-term effects of infrastructure policy in Ontario. Over the 50 year timeframe of this study, the population in Ontario is expected to change significantly. Therefore, the first component required is a demographic model to estimate the population from the present day until 2061. The demographic model considers four primary processes: birth, death, migration, and aging. Historically observed trends, such as decreasing mortality rates, are preserved in the model.

The second key component is the economic model. It is coupled to the demographic component through detailed modelling of the labour force. The basis of the economic production model is a Cobb-Douglas (23) function which relates the total economic production ( $Y$ ) to the labour capital ( $L$ ), private capital ( $K$ ) and public capital ( $G$ ) stocks.

$$Y = \alpha K^{\beta_K} L^{\beta_L} G^{\beta_G}$$

The elasticities of production,  $\beta_{\{K,L,G\}}$ , used in this study are from Macdonald (15). The elasticities of production for private and labour capital used were  $\beta_K = 0.31$  and  $\beta_L = 0.69$  respectively. The elasticity of production for public capital used was  $\beta_G = 0.1$  though Section 3.8 looks at the sensitivity of the results to this value. The multifactor productivity term,  $\alpha$ , accounts for changes in productivity due to other contributions such as improvements in technology. The stock of public infrastructure is governed by the two infrastructure policy parameters shown in Figure 1 and Figure 2: the total investment in infrastructure as a percentage of GDP, and the fraction of total investment that is allocated to maintenance. Note that these values include the contributions from the federal government spent in Ontario, those originating from

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the Ontario provincial government, and all spending by municipalities within the province. The effect of maintenance upon the value of the infrastructure capital stock is captured through adjustments to the depreciation rate. Higher levels of maintenance reduce the depreciation rate of infrastructure towards a lower, non-zero limit. Since public infrastructure is used by all industries in the economy, there is also an effect whereby increased production results in an increased depreciation rate due to greater wear and tear. This is the approach used in other studies to capture the importance of maintenance in infrastructure policy decisions (11; 24). Since private capital is not shared across industries, its evolution is governed simply through new private investment and a depreciation rate based on historical estimates.

Labour capital is derived from real average wages (by age and sex) and the employment rate in the population. As the economy grows, new employees are hired depending on availability, which is constrained by the demographic model. Real wages are adjusted according to the demand for employment with higher demand resulting in larger increases in real wages. Employee hiring and retirements are modelled based on historical trends in the labour force.

Infrastructure policy affects government expenses directly through funding of infrastructure projects, and also indirectly through tax revenues. A more productive economy will generate more taxable profits and income requiring lower tax rates for the same dollar value of infrastructure investment. By contrast, a higher level of infrastructure investment at the same size of economy requires higher tax rates. Governments must be able to fund government salaries, infrastructure investment, and other services. If sufficient revenue is unavailable, tax rates are adjusted to work toward eliminating the deficit, while if a surplus is present, the government will adjust tax rates to reduce the surplus.

Based on studies which correlate production growth to public infrastructure investment, the target growth in production is set to match the growth rate of public infrastructure. However, the actual growth that can be achieved is constrained by the rate at which the labour force can change (which is coupled to the demographic model), and the ability of private industry to invest in private capital.

The net result is a complex, highly coupled set of differential equations that connects many different aspects of the overall economy. For example, if production rises, the government will receive more taxation revenue, and may reduce taxes in response if it has a surplus. In addition, since overall revenue is higher, more government funding is available for infrastructure investment which may further increase production. However, if an increase in production requires more employees, the number of employees is limited by the demographic population. A shortage of employees may eventually feed back to government tax rates through limitations in production, which reduces government revenue.

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The system of differential equations is solved using an adaptive time-step Runge-Kutta integrator and uses actual historical data for the initial conditions. The entire model is connected to an optimization framework which allows one to determine the policy parameters which maximize (or minimize) a given model output. For example, the infrastructure policy parameters which maximize the real GDP in 2060 can be readily determined.

As the goal of this study is to capture the macroeconomic relationship between infrastructure investment and economic growth, different types of infrastructure and industries are not distinguished within the model. Similarly, all levels of government are consolidated into a single government entity which has average effective tax rates that accord with the total paid by employees and employers. The primary factor driving these simplifications is the lack of data related to the interaction between various infrastructure and industry types. While studies have examined some pairwise connections between specific industry types and specific infrastructure classes, in particular between the transportation industry and transport infrastructure (e.g. 25; 26), the general impacts are unknown. For example, the impact of water system infrastructure upon productive capacity of the transportation industry is unknown. However, data do exist when looking at infrastructure as a whole and its relationship with total production (8; 15; 24) .

In addition, unlike recent stimulus funding designed to directly enhance economic activity, the infrastructure policy parameters in the model are varied relatively slowly in time, allowing the economy time to adjust. As a result, potential inflation-output trade-offs are minimized and the model does not need to be expanded to include monetary policies (27).

## 2.2 Data Quality and Assumptions

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### 2.2.1 DATA QUALITY

All of the data used in this study were obtained from the Statistics Canada CANSIM database. Appendix B provides a detailed list of the data used and the corresponding sources in the CANSIM database. Generally, data exist up to 2009, however, due to data collection and processing, maintenance data are only current up to 2008. Furthermore, Statistics Canada changed its reporting criteria for capital investment and maintenance in 1994. It was assumed that the ratio of maintenance to total investment would be consistent under either definition.

### 2.2.2 ASSUMPTIONS

Many economic processes are difficult to model, and in the context of this study, would have little impact on the overall conclusions. For example, internal decisions within a corporation about whether to invest revenue in new capital or keep it as profit are outside the scope of this model. Therefore, historical behaviour is used to approximate these processes in the future and are provided as exogenous inputs to the model. A total of six such exogenous inputs are used in this model. These include:

- Pre-tax profits for corporations
- Non-tax revenue for governments
- Government expenses not associated with wages or infrastructure
- Private capital depreciation rates
- Multi-factor productivity
- Consumption not associated with infrastructure or private investment

Appendix C.3 provides the supporting data for all of the assumptions used. In addition, it is assumed that a government will always attempt to eliminate any surplus or deficit solely through changes in tax rates. In practice, if a government were to generate a deficit due to increased infrastructure investment, it may also elect either to carry the deficit, or to reduce investment in other areas. However, in this analysis it was assumed that neither of these would occur.

## 3.0 Detailed Results of Infrastructure Investment Policies

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The recent and proposed changes in the levels of infrastructure investment in Ontario present the opportunity to examine the potential economic impact of changes in infrastructure policy.

Section 3.1 examines the potential impact on GDP growth of the recent changes in infrastructure investment in Ontario as policies have changed from the historically low levels from the mid-1990s, to the recent increases over the last eight years, and the potential of continuing the *Building Together* plan. Sections 3.2 and 3.3 then look at the target level of infrastructure investment that yields the best possible macroeconomic outcomes starting from the current state of Ontario's infrastructure today. Using the target infrastructure policy, Sections 3.4, 3.5, and 3.6 present the risks of not achieving the target infrastructure policies for individuals, businesses, and the government, respectively. Section 3.7 highlights the importance of stable funding. Finally, Section 3.8 examines the sensitivity of the conclusions to the elasticity of public capital.

### 3.1 Moving in the Right Direction

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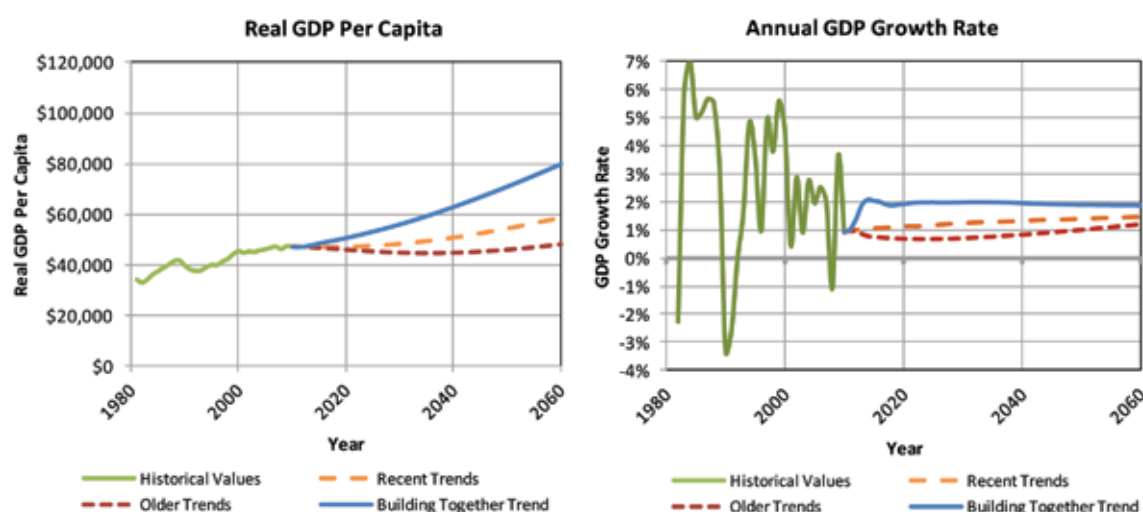
In order to examine the effect of recent and proposed infrastructure policies on the future economic prosperity of Ontario, four investment scenarios are considered.

Two trends are based on historical data. The **Recent Trend** policy uses the reported Ontario infrastructure investment and maintenance from 2003 onwards to project the infrastructure funding trends over the next 50 years. In contrast, the **Older Trend** policy uses the reported Ontario data from 1995 onwards to project the future trend which captures the historically lower levels of funding during the 1990s. Neither the Recent Trend policy nor the Older Trend policy includes the recently announced Building Together 10-year plan.

The **Building Together** policy estimates the funding level required to achieve the promised \$35 billion in infrastructure investment over the next three years and assumes that the same level of investment would be maintained over the next 50 years. Figure 3 shows how the recent increases in infrastructure investment levels do yield greater economic growth. As shown in Table 1, moving from the Older Trend to the Building Together Trend results in an average annual real GDP growth gain of over 1%. The **Building Together, Relapse** policy follows the Building Together Policy for the 10-year timeframe of the plan, then infrastructure funding relapses to the Recent Trend values.

Policy	Average Real GDP Growth Rate
Older Trend	0.84%
Recent Trend	1.25%
Building Together	1.87%
Building Together, Relapse	1.30%

**Table 1:** Average annual real GDP growth under each scenario.



**Figure 3:** Per capita GDP (left) and annual real GDP growth rate (right) under the recent trend policy, the older trends policy, and the Building Together policy.

The recent increase in infrastructure investment during the late 2000s was a significant improvement over prior infrastructure funding policies. The continued increase in infrastructure investment promised through the *Building Together* Infrastructure plan has the potential to yield even greater economic growth. However, if after the 10-year timeframe of the *Building Together* plan elapses and infrastructure investment levels return to the recent historical levels, the majority of the economic gains are lost (as shown in Table 1). Therefore, in order to realize the maximum benefits from infrastructure investment, it is crucial that long-term policies be sustained.

While the Building Together Trend does yield significant benefits relative to the historical trends, it is possible that other investment strategies could yield even greater benefits.

## 3.2 The Target Policy: Zero Marginal Return Point

As infrastructure investment increases, it is expected that the macroeconomic benefit of further investment may start to decrease. The point at which marginal benefits are exhausted from infrastructure investment is referred to as the zero marginal return point. It is toward this point that infrastructure policy should move. This zero marginal return point may depend on which stakeholder is asking the question. That is, the point at which marginal benefits are exhausted from infrastructure investment from a corporate point of view may differ from an employee's perspective. In order to determine the zero marginal return point which is best from a broad macroeconomic point of view, the zero marginal return policy was considered from three different perspectives. These include:

- Societal point of view: maximum real GDP in 2061
- Employer point of view: maximum net profit after tax (NPAT)
- Employee point of view: maximum after-tax wages

A multi-dimensional maximization algorithm is used to determine the infrastructure policies that yield the largest real values for each of the quantities above.

Table 2 shows the three zero marginal return infrastructure policies obtained for each point of view. All three zero marginal return policies lie quite close to each other. This is a reassuring result since it means that by adopting the average policy, individual stakeholders will still be quite close to their own maximum. It also implies that there should be very little friction between stakeholders when deciding on infrastructure policy.

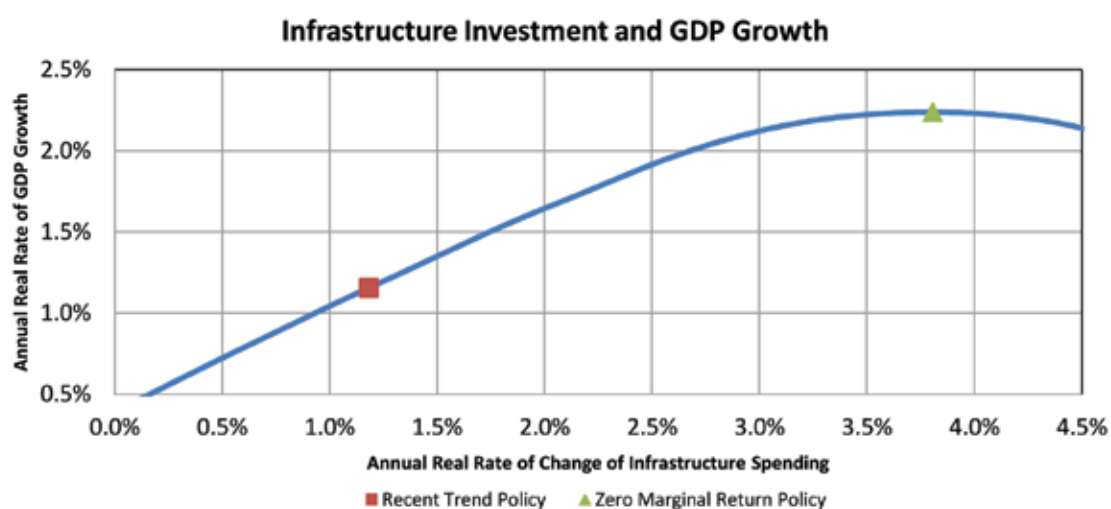
Maximization Target	Total Infrastructure Spending (% of GDP)	Maintenance Fraction (% of total infrastructure spending)
GDP	5.2%	22.1%
After-Tax Wages	5.2%	21.8%
Net Profit After Tax	4.8%	21.8%
<b>Average</b>	<b>5.1%</b>	<b>21.9%</b>

**Table 2:** Infrastructure policies for maximum real GDP, net profit after tax, and after tax wages. The final row shows the average adopted for the remainder of the analysis.

At the zero marginal return point, further increases in infrastructure investment yield no benefit. Figure 4 shows the relationship between average annual real rate of infrastructure investment growth compared to the average annual real rate of GDP growth by 2061. At the zero marginal return point, any change in infrastructure investment – whether an increase or decrease – results in a lower rate of GDP growth. However, around this point, the decrease in GDP growth rate would be relatively small. In contrast, in the region around the recent trend policy, the rate of GDP growth is very sensitive to changes in infrastructure investment. Even relatively small increases in infrastructure investment result in a significant change in the rate of GDP growth.

The increase from the current trend policy to the zero marginal return policy represents an increase in total infrastructure investment of 68%. At 194% of current levels, the net increase in maintenance is even greater, since both the total infrastructure investment and the fraction of that devoted to maintenance have increased.

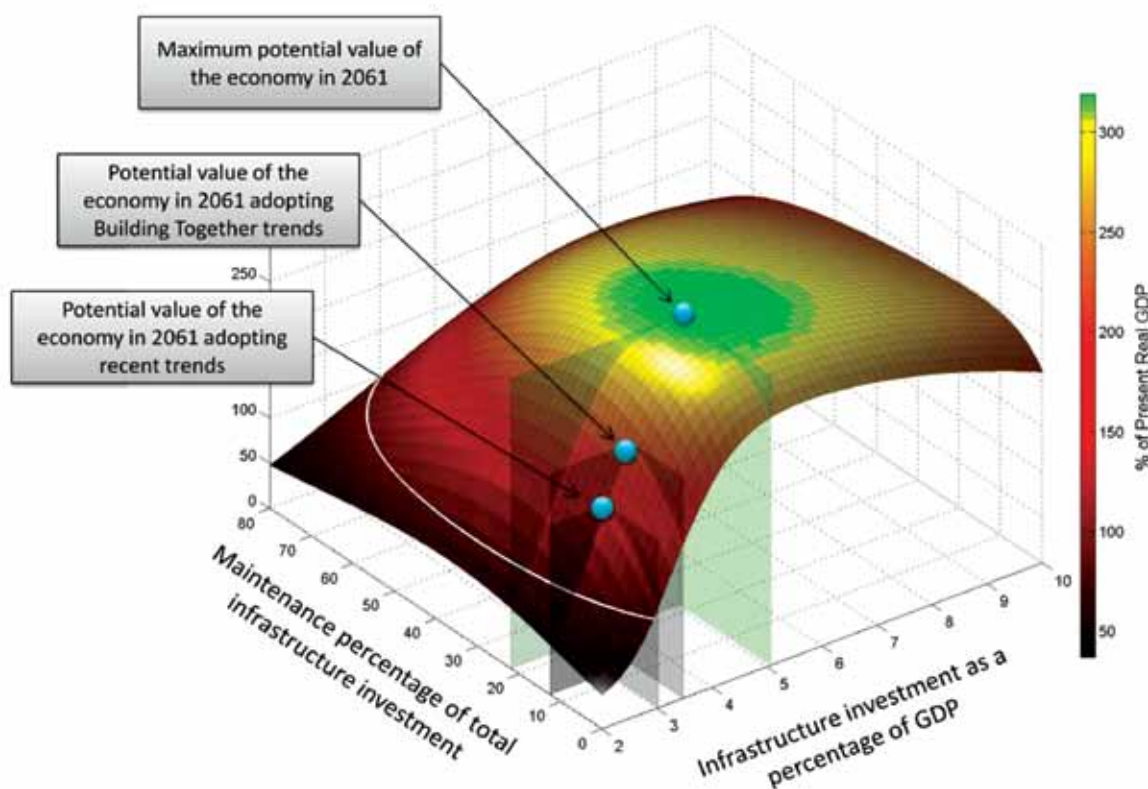
It is important to note that in practice one would never want to exactly reach the zero marginal return point. As one approaches it, the incremental return on investment decreases. Therefore, unless all other factors that drive economic growth are also at their respective zero marginal return points, investments in other areas would likely yield greater returns. In addition, as the incremental benefits are quite small, the risks associated with changes in project budget or incompletely realized gains become greater. Therefore, the policy using the zero marginal return point is called the **Target Policy**. That is the policy for which, given the option, one wants to aim.



**Figure 4:** The relationship between average annual real rate of change of infrastructure and the real rate of GDP growth. The triangle indicates the results if the current trend infrastructure policy is followed and the circle indicates the zero marginal return policy.

### 3.3 3D Illustration: Maximizing Ontario's Future Economic Potential Versus the Slippery Slope

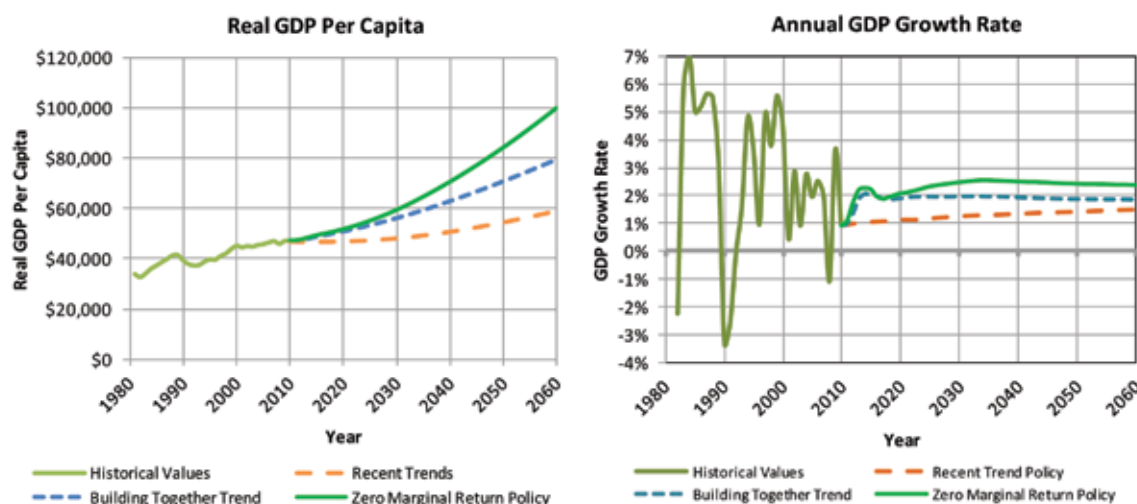
While the recent improvements in infrastructure investment and the 10-year *Building Together* plan do move infrastructure investment in the right direction, the Ontario economy is nonetheless at risk of failing to maximize its economic potential. The 3D illustration in Figure 5 shows the relationship between total public infrastructure investment (as a percentage of GDP), maintenance investment and the 2061 real value of GDP as a percent of current value. An adequately funded, stable, long-term infrastructure policy secures the foundation of efficient long-term economic production (the plateau). It is evident that the adoption of the recent trend of about 3% of GDP for the next 50 years puts this foundation on a slippery slope, a place where small reductions in infrastructure investment or misallocations have a disproportionate impact upon the deterioration of economic growth. The Building Together trend moves it toward the plateau, but still remains on the steep slope. While one would not expect to exactly reach the Target Policy, ideally one would like infrastructure investment to reach the cusp of the plateau where small changes in policy would not have a significant impact on economic growth.



**Figure 5:** The real GDP in 2061 as a percentage of real GDP today in terms of total infrastructure spending and the maintenance fraction. The white line indicates no change in real GDP. The colour gradient highlights the percentage change in real GDP from today ranging from dark red, where the real GDP has decreased, to green, where the real GDP has approximately tripled.

A direct comparison of annual GDP growth rates, shown in Figure 6, highlights the difference in real GDP growth under the two scenarios. While the difference in any given year is at most 1.3%, the effects of compounding over 50 years result in a significant divergence in total real GDP by 2061. Table 3 summarizes the differences in annual real GDP growth under each policy.

While total real GDP provides a measure of the wealth of the economy as a whole, the real GDP per capita provides a better reflection of individual wealth. Figure 6 also illustrates the divergence of per capita GDP under the various policy scenarios. At risk is over 60 percent of the potential real per capita GDP by 2061.



**Figure 6:** Per capita GDP (left) and annual real GDP growth rate (right) under the recent trend policy, the Building Together policy, and the zero marginal return policy.

Policy	Average Real GDP Growth Rate
Recent Trend	1.25%
Building Together	1.87%
Target	2.32%

**Table 3:** Average annual real GDP growth under each scenario.

### 3.4 Fostering Better Real Wage and Employment Potential for Individuals

Employees and their employers have a stake in ensuring an adequately funded, stable, long-term infrastructure policy. At risk are significant real wage gains and future employment if the potential risk of the underinvestment identified were to occur.

In terms of real after-tax wages, when all future employees are taken into account – including those who immigrate and people born after 1995 – maintaining the recent trend policy over the next 50 years instead of reaching the target policy could mean a difference of 59 percent in average real wages by 2061. Figure 7 shows the increasing benefit of the zero marginal return policy in terms of the average after-tax real wages.

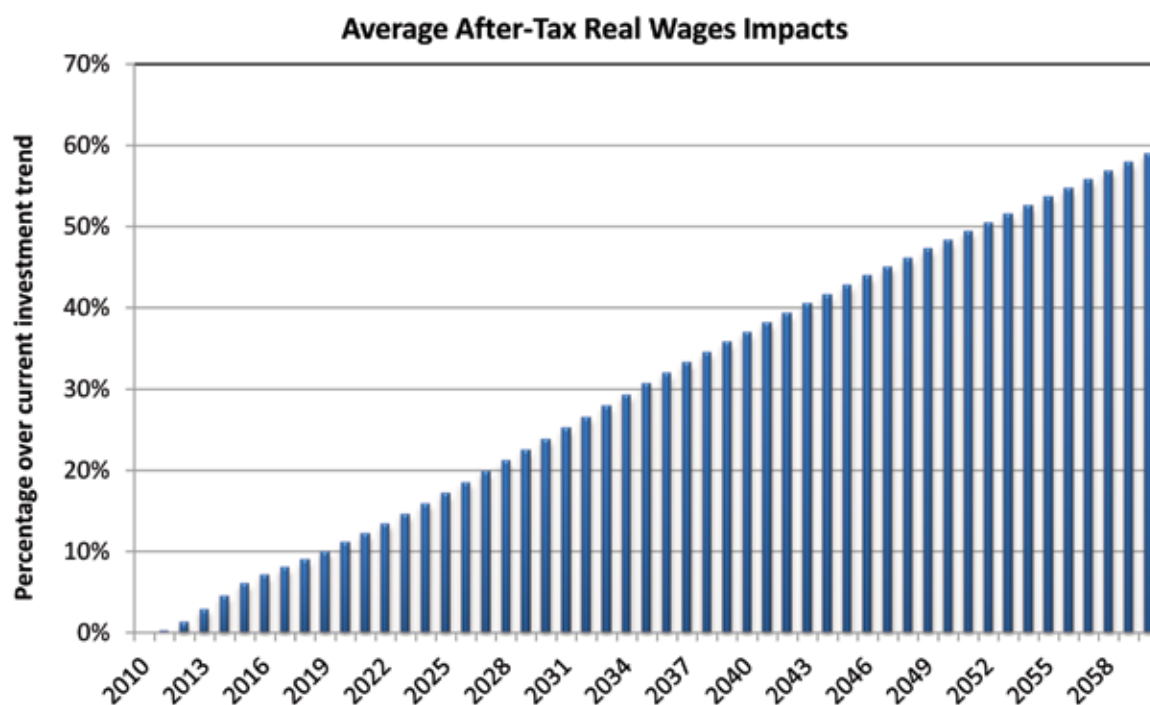


Figure 7: Increase in average after-tax wages under the target scenario instead of the recent trend policy.

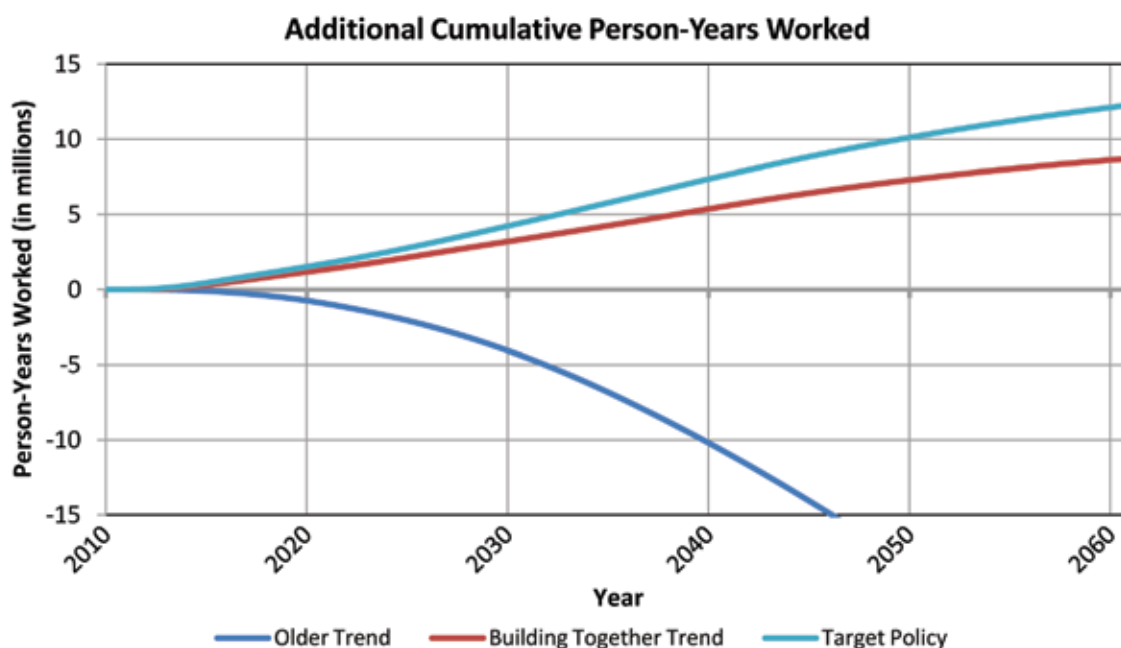
Due to the compounding nature of infrastructure investment and economic growth, those who are expected to be in the labour force the longest stand to see the greatest benefit. Put into the perspective of a lump sum valued today, a currently employed Canadian would be expected to pay the following for the identified long-term underinvestment in Canadian infrastructure:

Year of Birth	Present Value of Opportunity Loss	Future Value at Age 65
After 1995	Approximately \$57,392	Greater than \$407,864
1986 - 1995	\$57,392 to \$61,057	\$356,646 to \$407,864
1976 - 1985	\$60,718 to \$61,057	\$291,506 to \$356,646
1966 - 1975	\$46,825 to \$60,718	\$151,873 to \$291,506
1965 or Earlier	\$24,108 to \$46,825	\$52,823 to \$151,873

**Table 4:** Present value and future value of opportunity loss for employees.

These results are in present value terms which reflect the current worth of future after-tax wage benefits. Future increases in after-tax wages are discounted at the consumer borrowing rate, which was assumed to be 5.2% premium above the federal government borrowing rate, to reflect the time value of money. The future value of such benefits can then be easily calculated. For example, a fifteen year old in 2011 who later enters the workforce has an expected working life opportunity loss of \$60,000. If invested at a real interest rate of 4% for 50 years (presumed age of retirement), the future value by 2061 would be \$426,000. Note that while the present value of the opportunity loss for those born after 1995 is slightly less than that for those born later due to the longer discounting period, the future value of the opportunity loss by age 65 is considerably greater.

As shown in Figure 8, the greater productivity also drives greater levels of employment in addition to average wages. This is not only from the direct employment required to build and maintain infrastructure, but also due to the increased level of economic activity which increases the demand for employment. Over the next 50 years, over 12 million additional person-years of work would be generated if the target policy were reached. Falling back to the older trend policy could result in a loss of over 28 million person-years of employment.



**Figure 8:** Change in the cumulative number of person-years worked under each infrastructure policy relative to the recent trends policy.

In order to support the increased level of infrastructure investment, tax rates in the model do increase slightly. Figure 9 shows the tax rates under the current trend policy and the zero marginal return case. While tax rates do increase, they are generally below historical highs. However, even with higher tax burdens, there is a significant net benefit to employees. The present values of the difference in after-tax wages between the zero marginal return policy and the current trend policy exceeds the present value difference in taxes paid by 93%. In other words, for every dollar increase in taxes paid, employees are better off by \$1.93 in real after-tax wages.

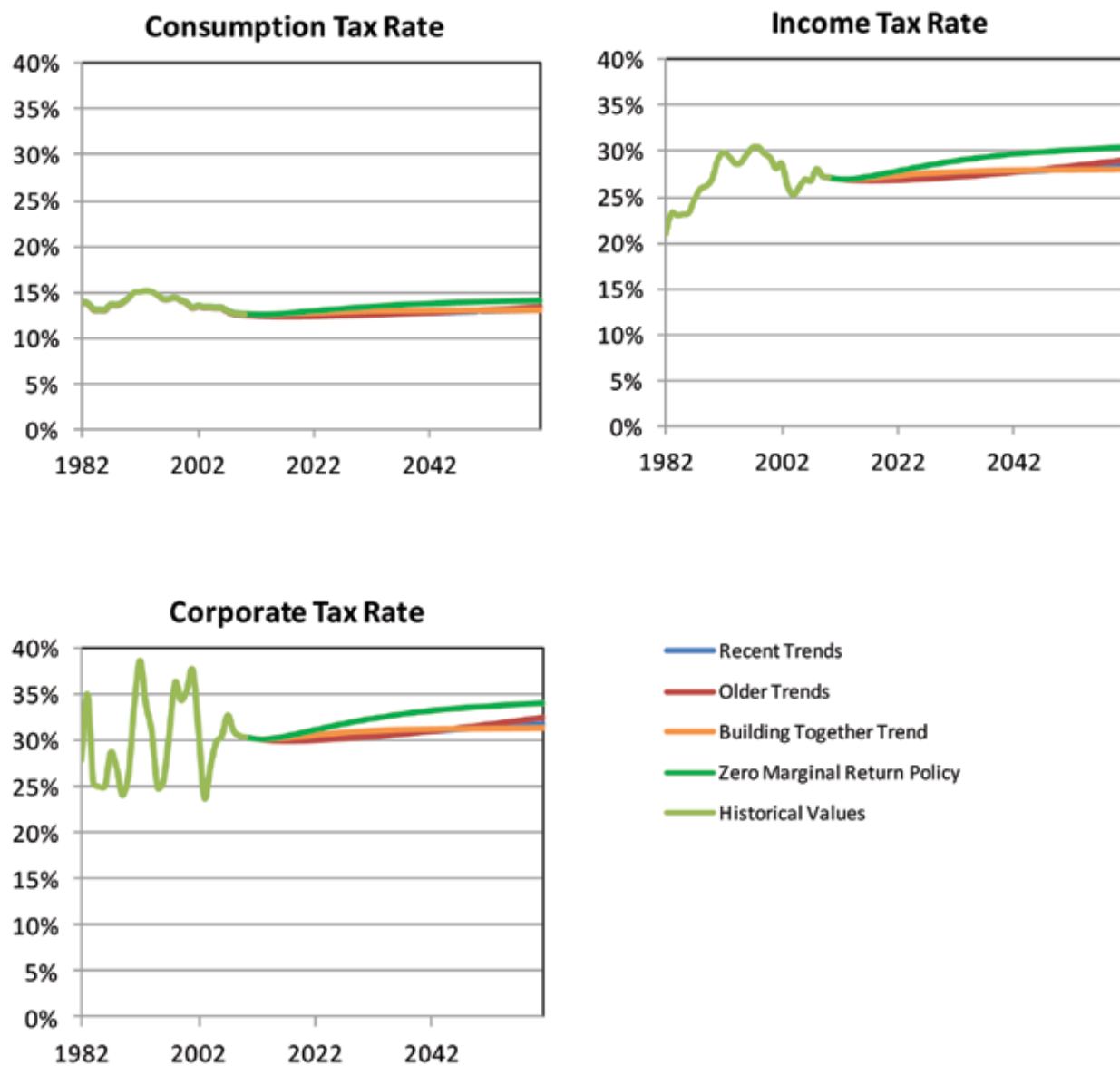
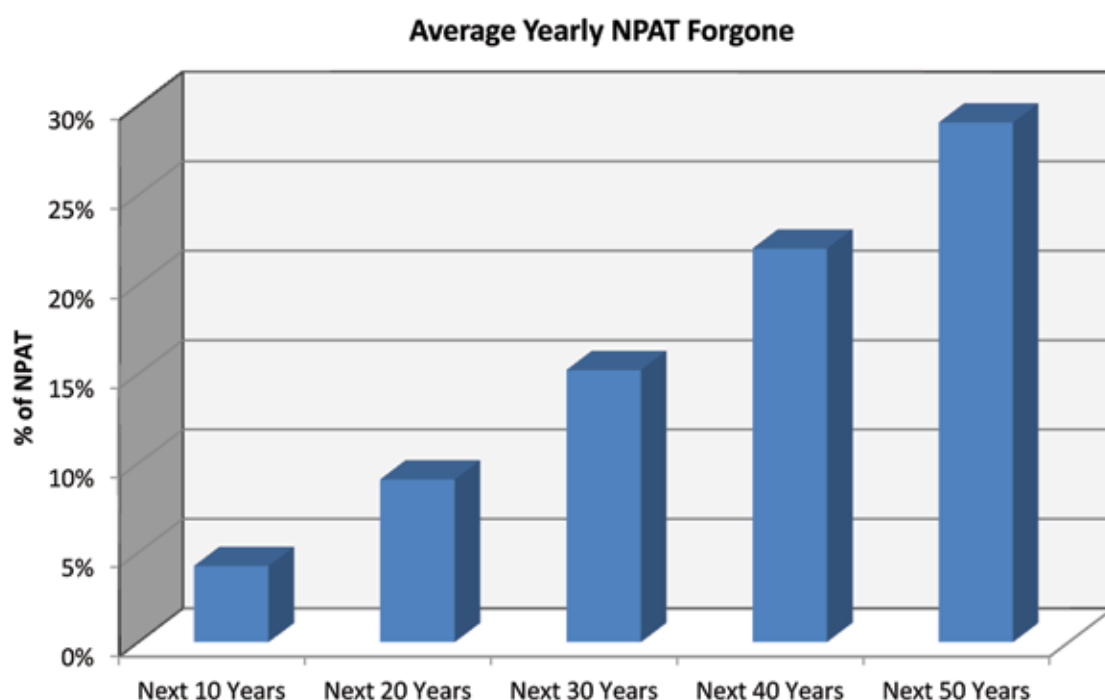


Figure 9: Personal, corporate, and consumption tax rates in the current trend policy and zero marginal return policy.

### 3.5 Increasing Net Profit After Tax Return Potential for Business

Employers are not immune from the dangers of long-term underinvestment in infrastructure. If the potential risk of underinvestment were to occur, it is estimated that employers are at risk of foregoing, on average, a 1% percent per annum increase of their NPAT. This impact accumulates over time as shown in Figure 10.



**Figure 10:** Average yearly net profit after-tax (NPAT) forgone if infrastructure policy was to follow the current trend rather than the zero marginal return policy.

Over the next ten years, this would mean an average NPAT of 4.3% foregone by each employer. Over the next 50 years, employer NPAT is at risk of being 29% less on average. That is, the longer the exposure to underinvestment, the larger the impact on Canadian employers over time. This has the undesirable consequence of placing the costs of infrastructure underinvestment disproportionately upon those businesses that have long-term investment plans in Canada.

## 3.6 Government Revenue Implications

It is important that the government view infrastructure spending as an investment rather than an expense. While greater government outlays may be required initially, the compounding benefits of improved infrastructure-related productivity result in significant returns. In particular, the present value of the additional infrastructure investment in Ontario required to reach the target policy over the next 50 years relative to the recent policy is \$832 billion. However, the present value of the cumulative revenue resulting from the increased economic prosperity of individuals and businesses is over \$3 trillion.

Relative to Recent Trends Policy	Total Additional Investment (\$m)	Total Additional Revenue (\$m)	Return On Additional Investment
Cumulative Real Value	\$1,567,102	\$7,293,202	365%
Cumulative Present Value	\$823,324	\$3,639,134	342%

**Table 5:** Government investment costs compared to additional government revenue.

Therefore, the government has significant potential tax revenue at risk by not investing sufficiently in public infrastructure.

### 3.7 Stable Infrastructure Investments are Preferable to Sporadic Spending

As shown in the Canadian analysis (11), unstable funding patterns have a significant detrimental effect on the efficiency on infrastructure investment. Using the Building Together trend as a reference, sporadic funding, even while maintaining the same long-term average level of funding, results in a reduction of annual GDP growth of 0.15%. Allowing infrastructure levels to return to the recent trends policy after the 10-year *Building Together* plan elapses results in an average loss of 0.57% of annual growth. Figure 11 shows how the average growth of GDP per capita over the next 50 years is less when less stable infrastructure investment policies are in place.

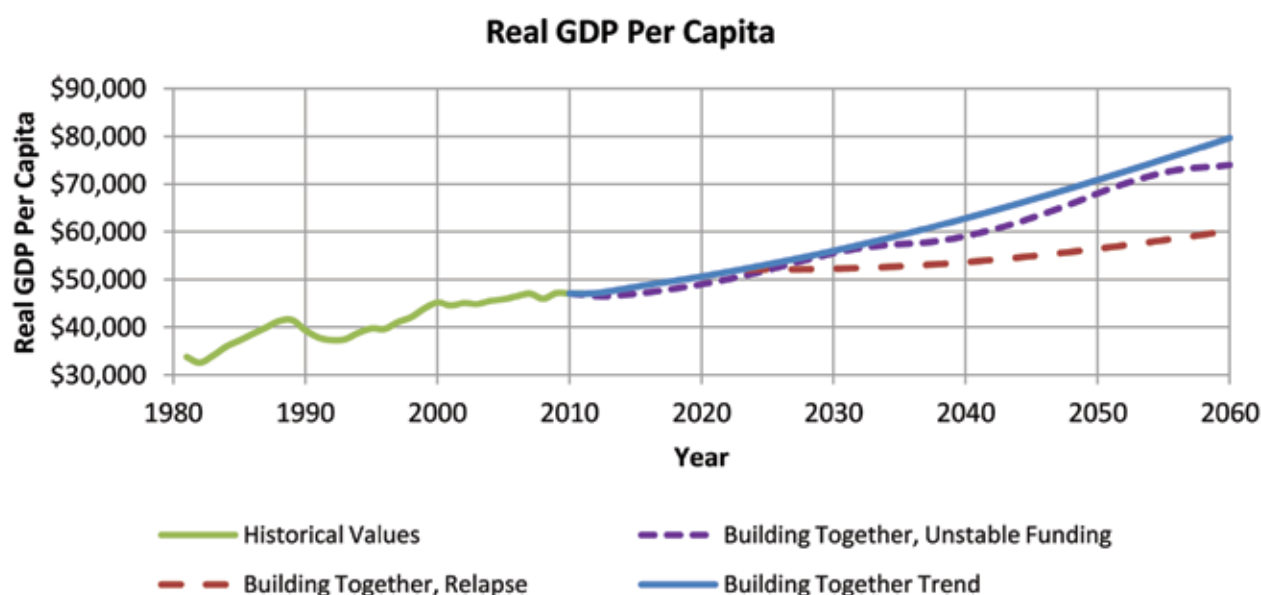


Figure 11: The impact of irregular funding on GDP per capita.

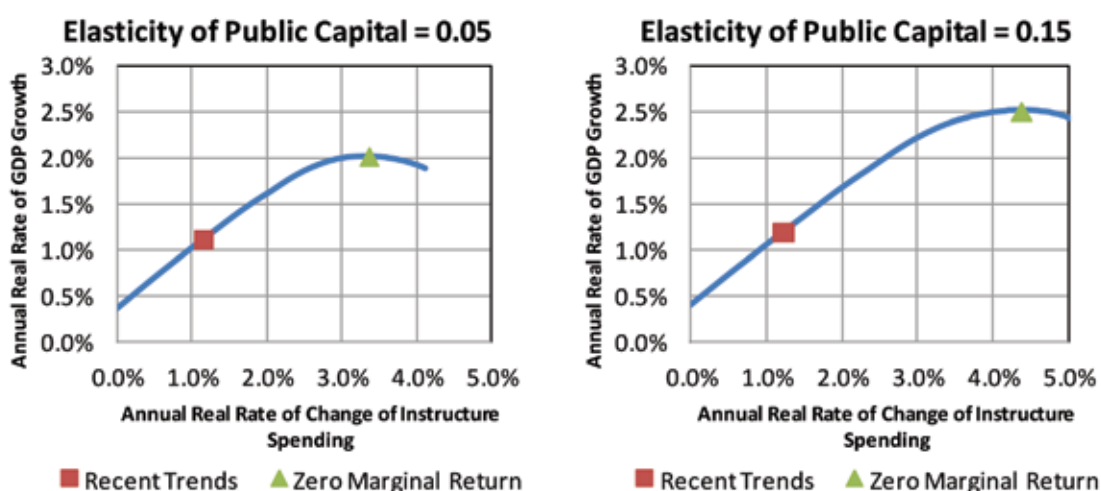
### 3.8 Sensitivity to the Elasticity of Public Infrastructure

The largest uncertainty when performing an analysis of the impact of infrastructure spending on the overall economy is associated with the elasticity of production for public capital,  $\beta_G$ . The value of 0.1 used in the analysis is the best estimate from Macdonald (15), however this study also provides a possible range of 0.05 to 0.15. A lower value would mean that public infrastructure contributes less to economic production. In the limit of  $\beta_G = 0$ , public infrastructure does not contribute at all to production. In contrast, a larger value would increase the importance of public infrastructure. In order to check the sensitivity of the conclusions to the elasticity of production of public capital, the basic analysis described in Section 3.2 is repeated for  $\beta_G = 0.05$  and  $\beta_G = 0.15$ , but with a focus upon GDP only. Table 6 shows the zero marginal return policies for GDP for each of the elasticities under consideration. The larger the elasticity, the greater the benefit is of investing in infrastructure. However, even in the case with the lowest elasticity, the total infrastructure investment which yields the largest GDP in 2061 is still significantly above the current trend values.

Elasticity	Total Infrastructure Spending (% of GDP)	Maintenance Fraction (% of total infrastructure spending)
0.05	4.7%	23.0%
0.10	5.1%	21.9%
0.15	5.6%	20.5%

**Table 6:** The average zero marginal return infrastructure points for various elasticities of production for infrastructure.

Figure 12 shows that in either case, the current trend policy lies significantly below zero marginal return policies. Therefore, while the exact numerical values of future GDP and wages may change under different values of elasticity of production for infrastructure, the general conclusion that the current policy trend puts significant economic growth at risk remains valid.



**Figure 12:** The relationship between average annual real rate of change of infrastructure and the real rate of GDP growth for elasticities of 0.05 (left) and 0.15 (right). The triangles indicate the results if the current trend infrastructure policy is followed and the circles indicate the zero marginal return policy.

## 4.0 Conclusions

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### 4.1 OVERVIEW

The recent improvements in infrastructure investment in Ontario, along with the 10-year *Building Together* plan, are moving infrastructure policies in the right direction. Compared to older trends, the recent infrastructure policy trends from 2003 to the present day could yield an increase in the average annual real GDP growth rate of 0.4%. If the trends indicated from the *Building Together* Infrastructure Plan were to be continued over the next 50 years, an additional annual real GDP growth rate increase of 0.6% has the potential to be realized. These improvements in GDP growth also translate into greater wages and employment, corporate profits, and government revenue. Infrastructure investment could be increased from the current level of 3% of GDP (with 12% of that for maintenance) to up to 5.1% (with 22% for maintenance) before the marginal benefits are exhausted. Relative to the recent trend, over the next 50 years, such a scenario has the potential to:

- Increase after-tax wages by almost 60% with those entering the work force today having the equivalent of more than \$400,000 real wages earned by age 65;
- Increase net profits after tax by almost 30%, equivalent to a 0.7% annual increase;
- Increase employment by over 12 million person-years; and
- Result in \$7 trillion more in cumulative government revenue while costing only \$1.5 trillion (over the next 50 years)

Such returns on infrastructure investment require long-term stable planning. Sporadic funding, even if the long-term average level of investment is maintained, results in lower economic growth. In the extreme case of infrastructure investment relapsing to historical trends, the rate of economic growth falls considerably.

The macroeconomic analysis in this report considers only the relationship between infrastructure investment and key macroeconomic variables. It does not consider the details of infrastructure inventory currently on hand, or how such an inventory should change over time. The analysis, therefore, only considers whether the current long-term investment trend makes sense from a macroeconomic point of view.

Given the identified risk of infrastructure underinvestment, it is strongly recommended that further analysis be conducted that couples national infrastructure inventory and deficit estimates with macroeconomic policy analysis. Analysis combining these types of datasets is necessary to ascertain an actionable strategy that can mitigate the identified risk of infrastructure underinvestment in Ontario.

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## 4.2 LIMITATIONS

The conclusions of this study are heavily dependent on the assumption of a Cobb-Douglas production function using a single infrastructure capital quantity. In reality, there are many different types of infrastructure, each with a different impact on production in the economy. For example, the construction of a new highway may have a significantly different elasticity of production than a new arena. The relative amount of different infrastructure types may change over time, resulting in a different elasticity of production for infrastructure as a whole. The assumption of a constant elasticity of production effectively assumes that future investments in infrastructure will reflect the same productivity capacity as in the past.

The economic model considers Ontario as an isolated economy. Imports and exports are not considered. A larger increase in Ontario production would be possible if Ontario's trade surplus was allowed to grow. However, the inverse may also occur if increased imports were to lower domestic production requirements. Since international and interprovincial trade balances will depend on the behaviour of the economies outside Ontario, this is outside the scope of this project. It is also assumed that population growth is not influenced by economics. In particular, immigration policies are not influenced by changing labour market demands. In scenarios with higher growth, the demand for employees may exceed local availability which acts to increase real wages. Allowing immigration rates to increase in these situations would alter both the demographic and economic outcomes. However, this type of decision is largely political and modelling these scenarios is outside the scope of this study.

Finally, the impact of infrastructure on more intangible quantities such as quality of life is not addressed in this study. For example, improvements in transportation infrastructure may result in reduced commuting times, which may not affect companies directly, but would have a bearing on the overall quality of life for the employee. Similarly, community buildings such as arenas or community centres may not have a significant long-term impact on production, but could lead to a higher quality of life. Such benefits are not readily captured in a macroeconomic model.

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### **4.3 FUTURE RESEARCH**

An important direction of future research involves breaking down infrastructure assets into various classes (such as transportation, water systems, and community infrastructure such as arenas). A model with finer asset divisions, in conjunction with a detailed inventory of the existing infrastructure inventory, could begin to provide recommendations on the type of infrastructure that is most beneficial to the economy.

Closely related to the research into various infrastructure asset categories would be research into different private industry areas. Different types of infrastructure may benefit certain types of industry more than others, allowing fine-tuned infrastructure policies to be developed. However, significant research into the effect of each type of infrastructure on each industry would be required to support such modelling efforts. In this regard, this report is intended as an initial step in a larger project that can be expanded upon in the future with finer infrastructure and industry categories. The econometric modelling approach has the advantage of being able to apply sensitivity analysis and to use an expanded range of variables to investigate the dependence of economic growth upon unknown or poorly known quantities.

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## APPENDIX B. Data Sources

The data used in this study were obtained from the Statistics Canada Canadian Socio-Economic Information Management System (CANSIM). RiskAnalytica's version of the database is current as of October 2008 and was supplemented with updates from the CANSIM website<sup>1</sup>. Where the quantity is used directly in the mathematical model, the symbol used to represent it is also indicated.

Quantity	Description	CANSIM Table	Symbol
<b>Demographics</b>			
Population	The population of Canada and its provinces by age and sex from 1971 to 2007.	051-0001	$P_t^{ag}$
Births	The number of births in Canada and its provinces by sex from 1971 to 2007	051-0013	$B_t^{ag}$
Deaths	Number of deaths in Canada and its provinces by age and sex	051-0002	$D^{ag}$
Immigration	Immigration into Canada and its provinces by age and sex	051-0012	
Emigration	Emigration from Canada and its provinces by age and sex	051-0012	
<b>Economics For Ontario</b>			
GDP	Annual gross domestic product from 1961 to 2009	380-0001	$Y$
Pre-tax Corporate Profits	Annual pre-tax profits from 1961 to 2009	380-0001	$\Phi^{\text{Pre-tax}}$
Total Wages	Annual total wages from 1961 to 2009	384-0001	$L$
Real Average Wages	Real average wages (in 2006 dollars) by age and sex from 1976 to 2006	202-0407	$w^{ag}$
Labour force statistics	Employed, unemployed and non-labour by age and sex from 1976 to 2007	282-0002	$E^{ag}, U^{ag}, N^{ag}$
Government Employees	Public sector employment by age and sex from 1976 to 2007	282-0008	$E_G^{ag}$
Capital	Public and private capital stocks	031-0002	$G, K$
Investment	Public and private capital investment	031-0002	$I_G, I_K$
Infrastructure Maintenance	Government investment on infrastructure capital, repair and maintenance from 1956 to 1994, and 1994 to 2009	029-0005, 029-0035	$M$
Government Accounts	Government expenses and revenue from 1981 to 2009	384-0004	$E, R$
Consumer price index	Consumer price index from 1914 to 2009	326-0021	

<sup>1</sup> <http://cansim2.statcan.ca/>

## APPENDIX C. Technical Model Details

### C.1 DEMOGRAPHIC MODEL

The demographic model incorporates birth, deaths, migration, and aging to model the future population of Canada.

#### C.1.1 BIRTH

The birth rate is assumed to be proportional to the number of females between the ages of 15 and 45,

$$\dot{B}^g = \beta^g \sum_{a=15}^{45} P^{a, \text{female}}$$

where the proportionality constant is assumed to follow an decreasing trend estimated from the historical values.

#### C.1.2 DEATH

Death is handled in a manner similar to birth. For each age group, there is a rate coefficient characterizing their likelihood of death.

$$\dot{D}^{ag} = \mu^{ag} P^{ag}$$

Again, the values of  $\mu^{ag}$  are assumed to follow a decreasing trend based on historical values.

#### C.1.3 MIGRATION

Immigration and emigration have a significant impact on the growth of the Canadian population. Unlike birth and death, where trends of decreasing births and deaths are apparent, no such trend exists in the immigration and emigration rates. Therefore, immigration and emigration rates per capita,  $\alpha_{\text{Imm}}$  and  $\alpha_{\text{Em}}$  respectively, are assumed to be a constant and based on the historical average. Therefore,

$$\dot{P}_{\text{Migration}}^{ag} = \alpha_{\text{Imm}} P^{ag} - \alpha_{\text{Em}} P^{ag}$$

#### C.1.4 AGING

The last component in the demographic model is the aging of the population. The aging model adopted is

$$\dot{P}^{ag} = \frac{P^{(a-1),g}}{\Delta_{a-1}} - \frac{P^{ag}}{\Delta_a}$$

where the first term describes the people aging from age group  $a-1$  into age group  $a$ , and the second term describes the people aging out of age group  $a$  into  $a+1$ . The width of age group  $a$  is  $\Delta_a$ .

## C.2 ECONOMIC MODEL

Private production is the primary driver of the economy. A simple, but surprising robust, method to model private output is to use a Cobb-Douglas model (23) which relates the amount of capital available in different classes to the rate of production. It states that:

$$Y = \alpha \prod_i K_i^{\beta_i}$$

where  $Y$  is the rate of production,  $K_i$  is the value of capital class  $i$ ,  $\beta_i$  is the elasticity of capital class  $i$ , and  $\alpha$  is the multi-factor productivity term. The multi-factor productivity term accounts for the increasing productivity per capital unit due to non-tangible effects such as technological advancements. Two classes of capital are always considered: private capital,  $K$ , and labour capital,  $L$ . To account for the relative productivity of employees of varying experience, labour capital is defined using average real wages and employment numbers such that:

$$L = \sum_{ag} E^{ag} w^{ag}$$

where  $E^{ag}$  are the number of people employed in age group  $a$  of gender  $g$ , and  $w^{ag}$  is the average real wage paid to a person in that group. In order to capture the effects of infrastructure upon production, public capital,  $G$ , is a third class of capital considered in the economic model. Therefore, the production function used is

$$Y = \alpha K^{\beta_K} L^{\beta_L} G^{\beta_G}$$

An extensive analysis of the role of public capital in Canadian production (15) found reasonable elasticities of capital to be:

$$\beta_K = 0.31$$

$$\beta_L = 0.69$$

$$\beta_G = 0.1$$

Using these elasticities, along with the historical capital values and GDP, the historical multifactor productivity factor can be calculated.

### C.2.1 PUBLIC AND PRIVATE CAPITAL

The dynamics of public and private capital are based upon modelling done by Dioikitopoulos and Kalyvitis (24; 8). To determine how production changes over time, the time derivatives of the capital classes are required. For public and private capital, new investment will act to increase capital values, while depreciation will act to decrease capital. In particular:

$$\begin{aligned}\dot{K} &= I_K - \delta_K K \\ \dot{G} &= I_G - \delta_G G\end{aligned}$$

where  $I_K$  and  $I_G$  are new investments in private and public capital, and  $\delta_K$  and  $\delta_G$  are the depreciation rates of private and public capital. The historical trend of the private depreciation rate is extrapolated into the future.

The depreciation rate of public capital has an additional influence which affects its value. As production increases, there is increased stress placed upon the public infrastructure. For example, as factories increase output, there is an increased burden on the transportation infrastructure causing it to depreciate at a faster rate. To compensate for this additional wear-and-tear, governments can perform maintenance on the infrastructure which acts to reduce its depreciation rate. To account for these effects, the depreciation rate of public capital is taken to be a function of both maintenance and production (24). Therefore, the equations governing the rate of change in public capital are:

$$\begin{aligned}\dot{G} &= I_G - \delta_G \left( \frac{M}{Y} \right) G \\ \delta_G(x) &= (\delta_G^{\max} - \delta_G^{\min}) e^{-\lambda x} + \delta_G^{\min}\end{aligned}$$

The parameters  $\delta_G^{\max}$ ,  $\delta_G^{\min}$ , and  $\lambda$  can be estimated using a least-squares fit from historical data. Section C.3 presents the results of the fits for  $\delta_K$  and  $\delta_G$ .

While government revenue is required to fund infrastructure projects, the fraction of production devoted to infrastructure,  $\tau$ , is a primary policy parameter.

$$\tau = \frac{M + I_G}{Y}$$

The relative split of infrastructure between maintenance and new investment defined as:

$$\mu = \frac{M}{M + I_G}$$

is the second infrastructure policy parameter.

The total amount of private investment can be determined through the resource constraint equation

$$Y = C + I_k + I_G + M$$

When consumption is defined according to this decomposition of production, the historical ratio:

$$\sigma = \frac{C}{Y}$$

is relatively constant (see section C.3.1). Solving for the amount of private investment yields:

$$I_k = Y(1 - \tau - \sigma)$$

Unfortunately, as the total private investment must be positive, this form does not allow  $\tau + \sigma > 1$ . However, differentiating yields:

$$\dot{I}_k = \dot{Y}(1 - \tau - \sigma) - Y(\dot{\tau} + \dot{\sigma})$$

which has no constraints and  $I_k$  becomes an integrated quantity.

### C.2.2 TARGET PRODUCTION GROWTH

The rate of growth of production is closely tied to the rate of growth in infrastructure. Theoretical models tested on Canadian infrastructure (8) data have yielded a strong correlation between the rate of change of production and the rate of change of infrastructure. It was found that increases in private investment lag behind the increase in infrastructure investment indicating that it was the infrastructure growth supporting the production increases which in turn led to increased private investment rather than the other way around. Therefore, given the rate of change of infrastructure capital,  $\dot{G}$ , one can calculate what the target change in production should be:

$$\frac{\dot{Y}_{\text{Target}}}{Y} = \frac{\dot{G}}{G}$$

However, in order to reach this target production, other components of the economy must be able to respond accordingly.

### C.2.3 EMPLOYMENT AND WAGES

Given the target rate of production, differentiating the production function allows one to determine the target rate of change of labour capital given that the private and public capital derivatives are known. Differentiating and solving yields:

$$\dot{L}_{\text{Target}} = \frac{L}{\beta_L} \left( \frac{\dot{Y}_{\text{Target}}}{Y} - \frac{\dot{\alpha}}{\alpha} - \beta_K \frac{\dot{K}}{K} - \beta_G \frac{\dot{G}}{G} \right)$$

However, as the change in labour capital is constrained by demographics, it may not be possible to achieve the target labour capital growth. The rate of change in labour capital,  $\dot{L}$ , is a combination of changing employment rates and average wages.

$$\dot{L} = \sum_{ag} (\dot{E}^{ag} w^{ag} + E^{ag} \dot{w}^{ag})$$

There are several processes that affect changes in employment for each age/sex group. These include aging into and out of the age group, deaths, retirement, new hiring, and other processes such as migration. Similar processes affect the unemployed,  $U^{ag}$ , and the non-labour,  $N^{ag}$ , populations. Therefore:

$$\begin{aligned} \dot{E}^{ag} &= A^{ag}(E) - \dot{D}_E^{ag} - \dot{R}^{ag} + \dot{H}^{ag} + \Delta_E^{ag} \\ \dot{U}^{ag} &= A^{ag}(U) - \dot{D}_U^{ag} - \dot{H}^{ag} + \dot{S}^{ag} + \Delta_U^{ag} \\ \dot{N}^{ag} &= A^{ag}(N) - \dot{D}_N^{ag} - \dot{S}^{ag} + \dot{R}^{ag} + \Delta_N^{ag} \end{aligned}$$

where  $A^{ag}(X)$  is the aging operator for age group  $a$  on population  $X$ ,  $\dot{D}_X^{ag}$  is the rate of deaths among the population  $X^{ag}$ ,  $\dot{R}^{ag}$  is the retirement rate,  $\dot{H}^{ag}$  is the hiring rate,  $\dot{S}^{ag}$  is the rate people move from non-labour to unemployed and  $\Delta_X^{ag}$  is the rate of change due to other processes. If one assumes that deaths among each employment group occur at the same rate as the population overall, then:

$$\begin{aligned} \dot{D}_E^{ag} &= \frac{E^{ag}}{P^{ag}} \dot{D}^{ag} \\ \dot{D}_U^{ag} &= \frac{U^{ag}}{P^{ag}} \dot{D}^{ag} \\ \dot{D}_N^{ag} &= \frac{N^{ag}}{P^{ag}} \dot{D}^{ag} \end{aligned}$$

Similarly, if one assumes that the changes due to other processes occur equally across employment groups:

$$\Delta_E^{ag} = \frac{E^{ag}}{P^{ag}} \Delta^{ag}$$

$$\Delta_U^{ag} = \frac{U^{ag}}{P^{ag}} \Delta^{ag}$$

$$\Delta_N^{ag} = \frac{N^{ag}}{P^{ag}} \Delta^{ag}$$

The total change due to other process,  $\Delta^{ag}$ , can be determined by noting that:

$$\dot{P}^{ag} = \dot{E}^{ag} + \dot{U}^{ag} + \dot{N}^{ag}$$

so:

$$\Delta^{ag} = \dot{P}^{ag} - A^{ag}(P) + \dot{D}^{ag}$$

which is known from the demographic model. Retirement rates are assumed to be a constant fraction of the employed which can be modelled as:

$$\dot{R}^{ag} = \gamma^{ag} E^{ag}$$

where  $\gamma^{ag}$  can be estimated from historical data. Hiring rates,  $\dot{H}^{ag}$ , are taken to be a constant fraction of the non-employed population such that:

$$\dot{H}^{ag} = \alpha_H \beta^{ag} (U^{ag} + N^{ag})$$

where  $\alpha_H$  is the overall demand factor such that  $\dot{L}_{\text{Target}}$  can be met and  $\beta^{ag}$  is the hiring bias. As with  $\gamma^{ag}$ , the value of  $\beta^{ag}$  can be estimated from historical employment data. Finally,  $\dot{S}^{ag}$  is chosen to maintain a constant unemployment rate,  $\mu^{ag}$ , where:

$$\mu^{ag} = \frac{U^{ag}}{E^{ag} + U^{ag}}$$

Differentiating yields:

$$\dot{U}^{ag} = \frac{\mu^{ag}}{1 - \mu^{ag}} \dot{E}^{ag}$$

A final constraint placed on the hiring rate is that the net rate of change in the labour force rate does not exceed the maximum rate of change seen historically. The labour force rate is defined as:

$$\nu^{ag} = \frac{E^{ag} + U^{ag}}{P^{ag}}$$

Therefore:

$$\dot{v}^{ag} = \frac{\dot{E}^{ag} + \dot{U}^{ag}}{P^{ag}} - v^{ag} \frac{\dot{P}^{ag}}{P^{ag}} \leq \dot{v}_{\max}^{ag}$$

Under the assumption of a constant unemployment rate, this yields:

$$\dot{E}^{ag} \leq (1 - \mu^{ag}) (\dot{v}_{\max}^{ag} P^{ag} + v^{ag} \dot{P}^{ag})$$

If the rate of change in labour capital is still less than the target rate of change, real wages can be adjusted in an attempt to make up the difference. The change in real wages is assumed to be proportional to the current wages:

$$\dot{w}^{ag} \propto w^{ag}$$

Therefore:

$$\dot{w}^{ag} = \left( \frac{\dot{L}_{\text{target}}}{L} - \frac{1}{L} \sum_{ag} (\dot{E}^{ag} w^{ag}) \right) w^{ag}$$

Again, the rate of change in real wages is constrained by the rates of change seen historically.

#### C.2.4 CORPORATE PROFITS

Pre-tax corporate profits,  $\Phi^{\text{Pre-tax}}$ , are assumed to be a multiple of total production which are then taxed at a rate of  $\tau^{\text{Corp}}$ . Therefore:

$$\begin{aligned} \Phi^{\text{Post-tax}} &= (1 - \tau^{\text{Corp}}) \Phi^{\text{Pre-tax}} \\ \Phi^{\text{Pre-tax}} &= f^{\text{Pre-tax}} Y \end{aligned}$$

Section C.3.2 shows the calibration functions used for  $f^{\text{Pre-tax}}$ .

#### C.2.5 GOVERNMENT

Governments must attempt to balance their revenues with their expenses. Revenue primarily arises through taxation of personal income, corporate profits, and general production. However, revenue can also come from other sources such as investment income. Average tax rates are calculated based on total wages, total pre-tax corporate profits, and total production. Therefore, the rate at which the government collects revenue is:

$$R = L\tau^{\text{Income}} + \Phi^{\text{Pre-tax}}\tau^{\text{Corp}} + Y\tau^{\text{Production}} + R^{\text{other}}$$

Based on historical data shown in section C.3, it is assumed that  $R^{\text{other}}$  is a simple fraction of the total revenue:

$$R^{\text{other}} = f^{\text{NonTax}} R$$

Therefore, the total government revenue rate is:

$$R = \frac{1}{1 - f^{\text{NonTax}}} \left( L\tau^{\text{Income}} + \Phi^{\text{Pre-tax}} \tau^{\text{Corp}} + Y\tau^{\text{Production}} \right)$$

In the context of this project, government expenses consist of wages to government employees, funding of infrastructure, servicing of accumulated debt,  $D$ , and other expenses. Thus:

$$E = W_G + I_G + M + iD + E^{\text{other}}$$

It is assumed that other expenses are proportional to the total government wages so that:

$$E^{\text{other}} = \zeta W_G$$

and  $\zeta$  is estimated from historical data. The net rate at which the government accumulates a surplus is then:

$$S = R - E$$

In an attempt to balance the rate of revenue with the rate of expenses, the government must adjust tax rates. It is assumed that tax rates will be adjusted according to the size of the surplus or deficit relative to total revenue:

$$\dot{\tau}^k = -\alpha_T \frac{S}{R}$$

where  $\alpha_T$  is the tax response rate parameter.

### C.3 ECONOMIC CALIBRATION FUNCTIONS

Calibration functions account for unknown or un-modelled economic processes. For example, this study is not concerned with the manner in which corporations generate pre-tax profits. Therefore, the historical ratio between pre-tax profits and total production is used as a heuristic to account for this process. If there are consistent historical trends in the data, the value can be extrapolated into the future. As the last historical data value may not align with the long-term trend, the difference is smoothly absorbed through an exponential decay. If  $f_H(t)$  is the set of historical values which exist up to time  $t_H$  and the identified trend is  $\hat{f}(t)$ , then the calibration function is:

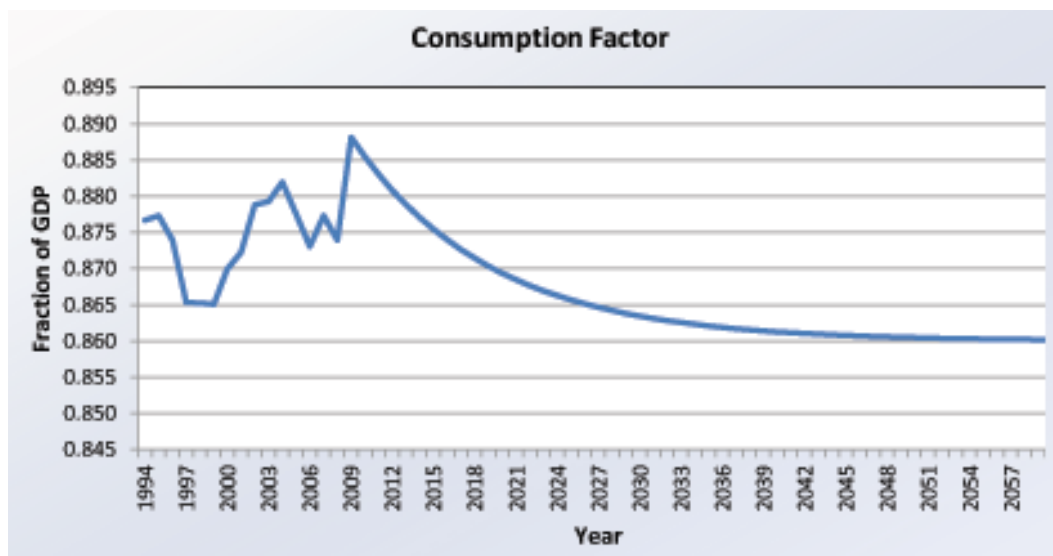
$$f(t) = \begin{cases} f_H(t) & t < t_H \\ \hat{f}(t) + (f_H(t_H) - \hat{f}(t_H))e^{-\lambda(t-t_H)} & t > t_H \end{cases}$$

### C.3.1 CONSUMPTION

The fraction of production consumed by personal, business, and government consumption is the consumption ratio. In the context of this model, it is all goods and services produced excluding government investment on infrastructure and new private capital investments:

$$f^{\text{Consumption}} = \sigma = \frac{C}{Y}$$

Figure 13 show the historical values and the trend extrapolated into the future.



**Figure 13:** The ratio of consumption to total GDP.

### C.3.2 CORPORATE PRE-TAX PROFITS

Pre-tax profits are assumed to be a fraction of total production:

$$f^{\text{Pretax}} = \frac{\Phi^{\text{Pretax}}}{Y}$$

Figure 14 shows that historically this ratio has ranged from a low of just under 6% to a high of over 14% with no noticeable long-term trend. Therefore, the average of the historical values is assumed to be the long-term trend.

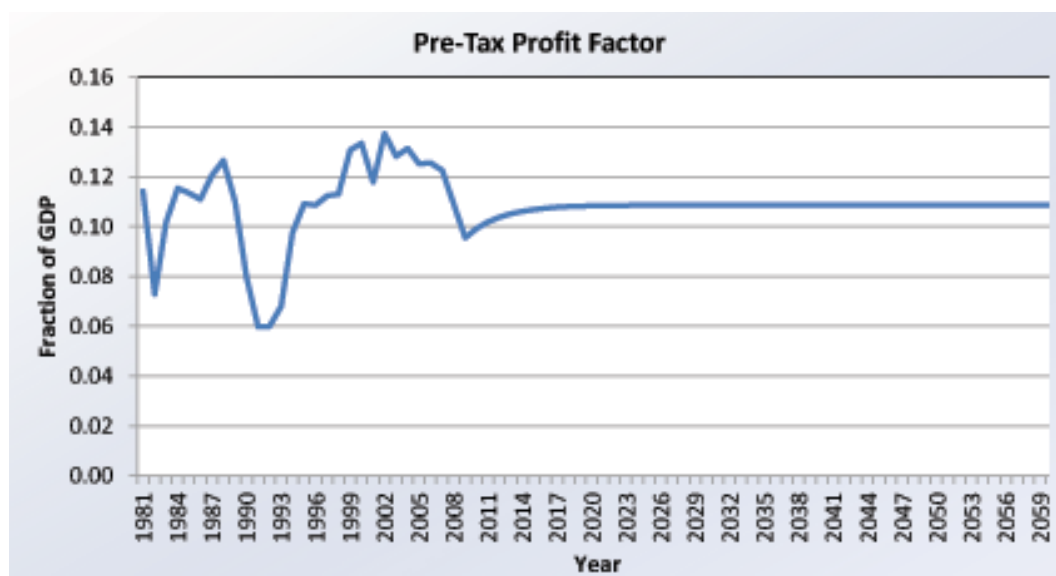


Figure 14: Pre-tax profits as a fraction of GDP.

### C.3.3 GOVERNMENT FACTORS

The government calibration factors consist of the non-tax revenue factor, and the “other expense” factor. Figure 15 and Figure 16 show the historical values and the extrapolation to the historical average for each factor respectively.

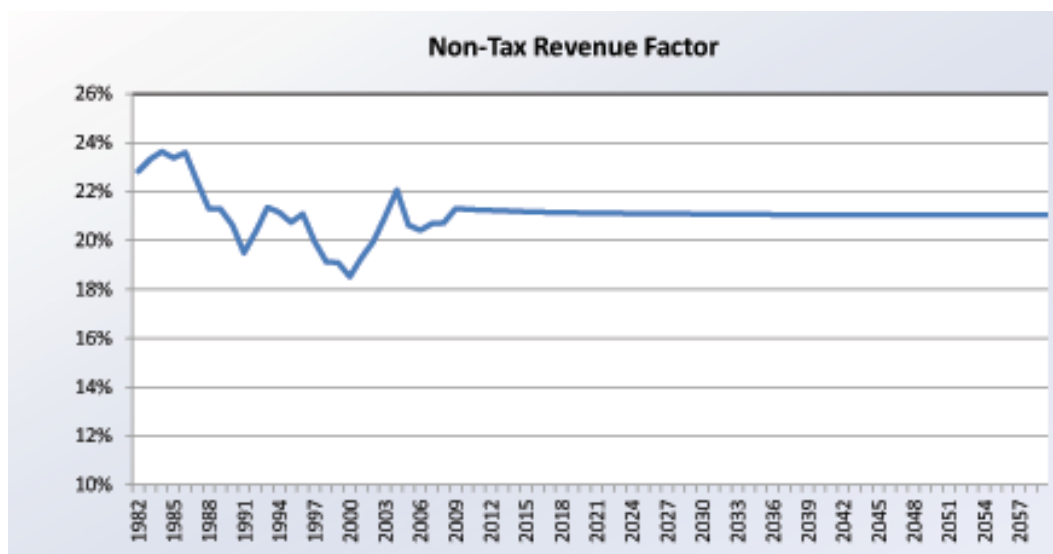


Figure 15: The fraction of government revenue from non-tax sources.

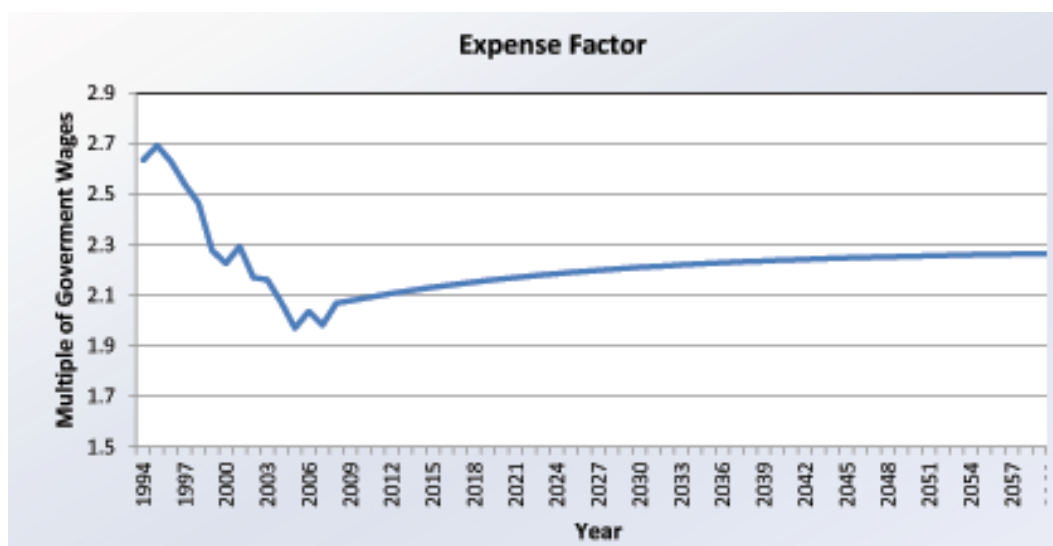


Figure 16: The government expense factors defined as unaccounted-for expenses as a multiple of government wages.

### C.3.4 DEPRECIATION FACTORS

#### PRIVATE CAPITAL DEPRECIATION

The rate of depreciation of private capital is estimated from the trend in the historical depreciation rates. As illustrated in Figure 17, there has been a consistent upwards trend in the depreciation rate. Therefore, this general behaviour is extrapolated linearly into the future.

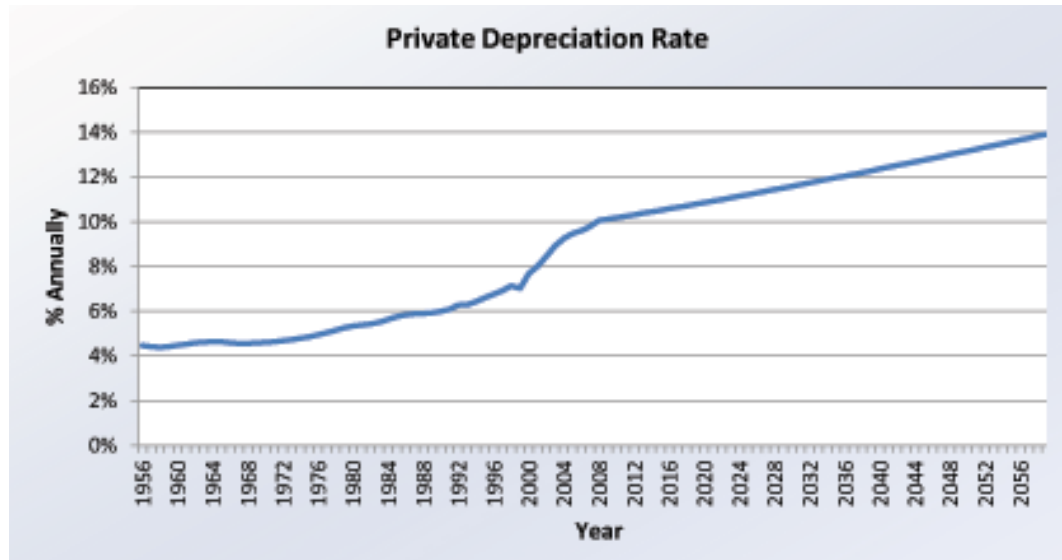


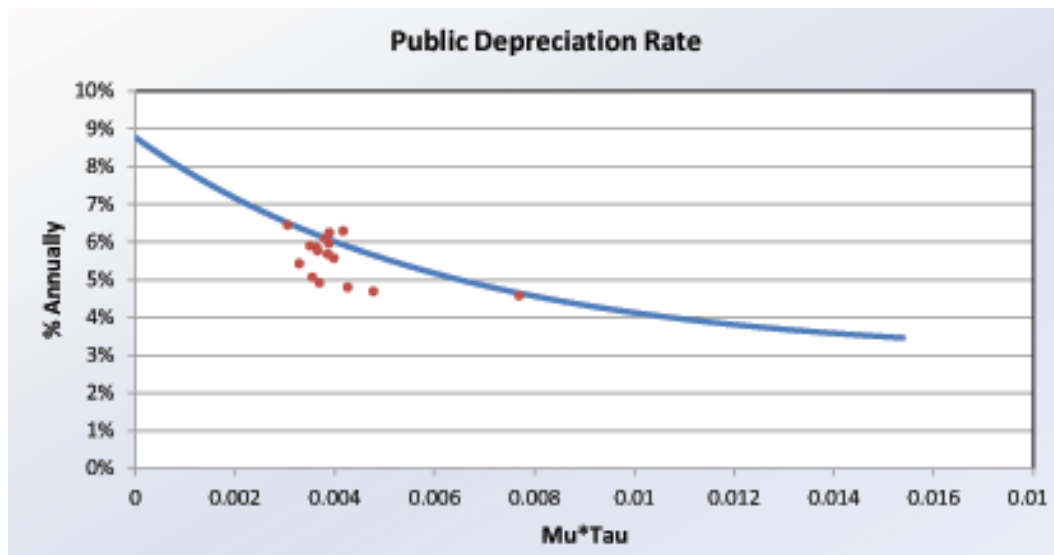
Figure 17: Depreciation rate of private capital.

#### PUBLIC CAPITAL DEPRECIATION

Figure 18 illustrates the dependence of the depreciation rate of public capital upon infrastructure maintenance investment and production. As total maintenance investment is  $M = \mu\tau Y$ , one sees that:

$$\delta_G\left(\frac{M}{Y}\right) = \delta_G(\mu\tau)$$

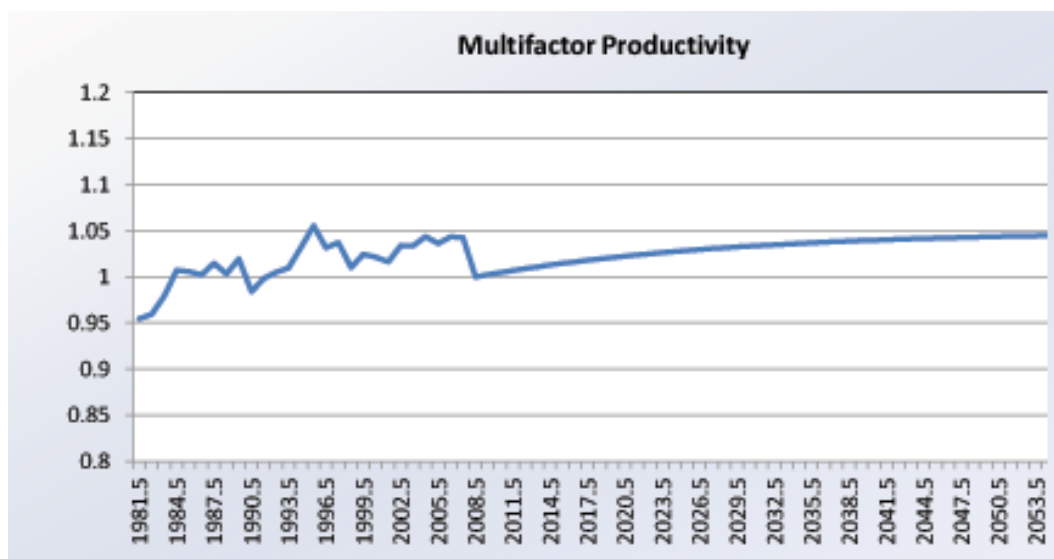
As the fraction of production spent on infrastructure maintenance decreases ( $\mu\tau \rightarrow 0$ ), the depreciation rate of the infrastructure increases. Conversely, if the maintenance fraction is increased, the depreciation rate will fall, but it cannot be decreased below about 4% per year. Therefore, increasing levels of maintenance will have diminishing returns.



**Figure 18:** Depreciation rate of public capital as a function of maintenance spending and production. The curve is the estimated value based upon Canadian data while the points are the observed Ontario values.

### C.3.5 MULTIFACTOR PRODUCTIVITY

The multifactor productivity has a direct impact upon future production in the model. The form adopted here extends the historical trend, while conservatively capping the value at 1.05.



**Figure 19:** Multifactor productivity factor.



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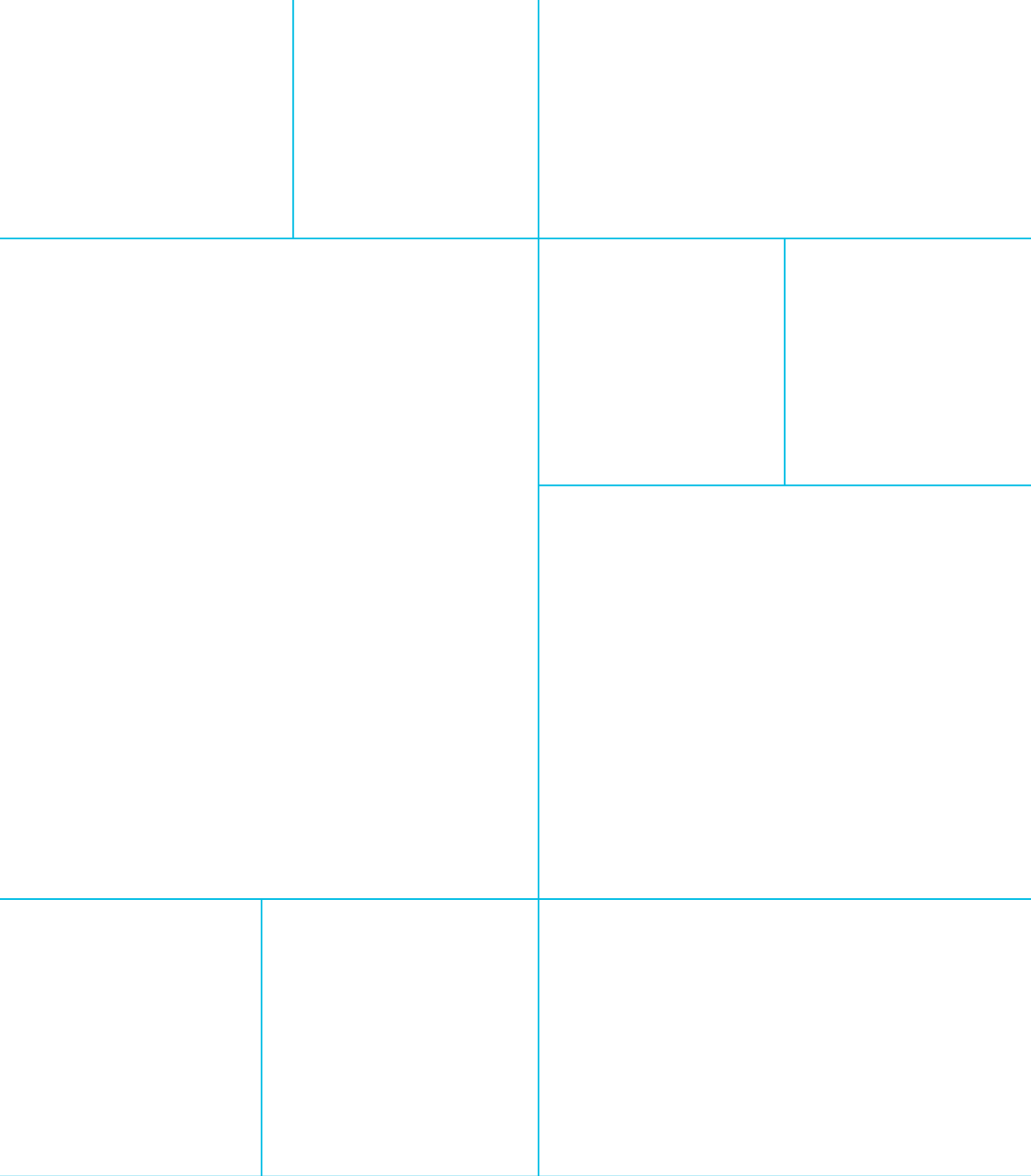
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The Residential and Civil Construction Alliance of Ontario (RCCAO) is an alliance composed of management and labour groups that represents a wide spectrum of the Ontario construction industry. The RCCAO's goal is to work in cooperation with governments and related stakeholders to offer realistic solutions to a variety of challenges facing the construction industry. For more information on the RCCAO or to view copies of other studies and submissions, please visit the RCCAO website at [www.rccao.com](http://www.rccao.com)

RCCAO members include: Carpenters' Union • Greater Toronto Sewer and Watermain Contractors Association • Heavy Construction Association of Toronto • International Union of Operating Engineers, Local 793 • International Union of Painters and Allied Trades, District Council 46 • Joint Residential Construction Council • LIUNA Local 183 • Residential Carpentry Contractors Association • Toronto and Area Road Builders Association

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