Journal of Infrastructure, Policy and Development (2018) Volume 2 Issue 2.
DOI: 10.24294/jipd.v2i2.839

ORIGINAL ARTICLE

On the effects of infrastructure investment on economic performance in Ontario(*)

Alfredo Marvão Pereira* and Rui Manuel Pereira

Department of Economics, The College of William and Mary, Williamsburg VA, Virginia, USA

ABSTRACT

Over the past decade, Ontario has seen a renewal in efforts to stimulate economic growth by investing in infrastructures. In this paper, we analyze the impact of public infrastructure investment on economic performance in this province. We use a multivariate dynamic time series methodological approach, based on the use of vector autoregressive models to estimate the elasticities and marginal products of six different types of the public infrastructure assets on private investment, employment, and output. We find that all types of public investment crowd in private investment while investment in highways, roads, and bridges crowds out employment. We also find that all types of public investment, with the exception of highways, roads, and bridges, have a positive effect on output. The range of results estimated for the impact of each of the different public infrastructure types is rather large. This suggests that an approach to the design of infrastructure investment policy that considers specific assets, as opposed to just general indiscriminate investment efforts, is required. Infrastructure investment in transit systems and health facilities display the highest returns for output and the largest effects on employment and labor productivity. In terms of the nature of the empirical results presented here, it would be important to highlight the fact that investments in health infrastructures, as well as investments in education infrastructures, are of great relevance. This is a pattern consistent with the mounting international evidence on the importance of human capital for long-term economic performance.

Keywords: *infrastructure investment; economic performance; vector autoregression; Ontario*
JEL Classifications: *C32: Time Series Models Multiple or Simultaneous Equation Models, E62: Fiscal Policy, H54: Infrastructures, Other Public Investment and Capital Stock.(*)*

1. Introduction

During the 1960s and 1970s, very substantial large-scale public works infrastructure projects were undertaken in Ontario, including the Trans-Canada Highway and Toronto's subway system. With the completion of these projects, growth in the public capital stock began to slow in the 1970s and continued at a slower pace through to the 1990s. Over the past decade, however, programs such as Re New Ontario - which is aimed at education and health-care infrastructure - and Move Ontario - which is aimed at increasing and improving public

This research was performed under the auspices of Deloitte Canada in the context of a research project sponsored by the Ontario Ministry of Infrastructure and released to the public in December 2017. The views expressed here do not necessarily reflect the positions of either of these institutions. We would like to thank the staff of the Ontario Ministry of Infrastructure and the Ontario Ministry of Transportation, Gianni Ciufo, Anita Shinde and, in particular, Kanishk Bhatia, for providing invaluable comments and suggestions. The usual disclaimers apply

ARTICLE INFO
Received: May 18, 2018
Accepted: July 13, 2018
Available online: November 9, 2018

***CORRESPONDING AUTHOR**
Alfredo Marvão Pereira, Department of Economics, The College of William and Mary, Williamsburg VA, Virginia, USA

CITATION
Pereira AM, Pereira RM (2018) On the effects of infrastructure investment on economic performance in Ontario(*). *Journal of Infrastructure, Policy and Development*, 2(2): 286-300. doi: 10.24294/jipd.v2i2. 839

transportation infrastructures - have renewed growth in public infrastructure spending. In addition to these programs, the Health Infrastructure Renewal Fund (HIRF) was established, in 1999, to assist public hospitals with the modernization of their health-care facilities and, in 2002, the Ontario strategic infrastructure financing authority act was passed to facilitate investment in clean water infrastructure, sewage treatment facilities, waste management infrastructures, and public transit among other infrastructure areas. The question now is where to go from here. Accordingly, the analysis of the potential effects of infrastructure investment in Ontario is a very timely issue.

In this paper, we analyze the impact of public infrastructure investment on economic performance in Ontario, considering six different types of public infrastructure assets. Despite the existence of a large body of literature on this topic, empirical evidence for Canada in general and Ontario, in particular, is rather scant or non-existent, especially at a more disaggregated level.

We use a multivariate dynamic time series methodological approach, based on the use of vector autoregressive (VAR) models, developed in Pereira and Flores (1999) and Pereira (2000, 2001). This approach was subsequently applied to the U.S. in Pereira and Andraz (2003, 2004, 2012), to Portugal in Pereira and Andraz (2005, 2006), and Pereira and Pereira (2018), and to Spain in Pereira and Roca-Sagales (1999, 2003). For other VAR-based applications with an international focus see, for example, Agenor *et al*. (2005), Batina (1998), Belloc and Vertova (2006), De Frutos *et al*. (1998), Demetriades and Mamuneas (2000), Ghali (1998), Kamps (2005), Lau and Sin (1997), Ligthart (2002), Mamatzakis (1999), Mittnik and Newman (2001), Otto and Voss (2002), and Sturm *et al*. (1999).

This econometric approach allows us to address the criticisms leveled against the univariate static production function approach often used in the literature following the seminal contributions of Aschauer (1989a, 1989b) - the problem of the endogeneity of all variables, the absence of a dynamic element, and the inability to establish causality - in a rigorous and comprehensive manner. It also brings a more precise conceptual focus to the debate about whether or not public infrastructure is productive and how productive it is. For surveys of the relevant conceptual and econometric issue, for example, Gramlich (1994), Romp and de Haan (2007), and Pereira and Andraz (2013). For general discussions of the economics of infrastructure, development and policy in a globalized world see, for example, Henckel and McKibbin (2017), Klein (2017) and Regan (2017).

Our approach highlights the dynamic nature of the relationship between infrastructure and economy. It does so at three distinct levels: (i) It explicitly addresses the contemporaneous relationships in the innovations in each variable, (ii) it incorporates the dynamic intertemporal feedback structure among the variables, and (iii) it accommodates the possible existence of long-run equilibrium relationships among the variables.

Finally, it should be pointed out that although our approach is eminently empirical, it is not theoretical. Indeed, our analysis is grounded in a dynamic model of the economy, and the econometric approach frames an economic understanding of the effects of public infrastructures on economic performance. In this model, the economy uses a production technology based on the use of capital and labor, as well as public infrastructure, to generate output. Given market conditions and the availability of public infrastructure, the private sector decides on the level of input demand and the supply of output. In turn, the public sector engages in public infrastructure investment based on a policy rule that relates public infrastructure to the evolution of the economic variables. The estimated VAR system can be seen as a dynamic reduced form system for a production function and three input demand functions - for employment and private investment as well as infrastructure investment (a policy function). This framework captures the role of public infrastructure investment as a direct input to production, its indirect affect on output through its effect on demand for labor and private capital, and as an externality in production.

This paper is organized as follows. Section 2 presents the basic economic and infrastructure data and the preliminary econometric results including the VAR model specification. Section 3 discusses the identification of exogenous shocks to public infrastructure investment as well as the measurement of their effects. Section 4 presents the main econometric results with respect to the economic impact of public infrastructure investment and provides some international comparisons. Finally, Section 5 presents a summary and some concluding remarks.

2. Data and preliminary empirical results

In this section, we present the data set used in this paper as well as the preliminary statistical results necessary to arrive at our main results to be discussed in Section 4. Although details of the data set and preliminary results in this section are omitted in this paper, they are readily available from the authors on request.

2.1. Data: Sources and description

Table 1 provides summary information about public infrastructure investment in Ontario as a percent of GDP in the region. Table 2 provides information on the composition of infrastructure investment by type of infrastructure. We consider data for Ontario from 1976 to 2011. This period was chosen due to limitations in the availability of a consistent, longer time series for employment data for Ontario.

Table 1. Public infrastructure investment in ontario-percent of GDP

Infrastructure Type	1976–2011	1976–79	1980–89	1990–99	2000–09
Government administration and other infrastructures	0.67	0.71	0.66	0.68	0.63
Health infrastructures	0.32	0.30	0.26	0.24	0.44
Highways, roads, and bridges	0.99	1.29	0.99	0.97	0.87
Education infrastructures	0.39	0.51	0.29	0.40	0.45
Transit infrastructures	0.18	0.13	0.17	0.14	0.18
Waste, water and wastewater infrastructures	0.20	0.19	0.22	0.16	0.20
Total	2.74	3.14	2.59	2.59	2.77

Source: IAG and authors' calculations, GDP: Gross domestic product

Table 2. Public infrastructure investment in Ontario – Composition`

Infrastructure Type	1976–2011	1976–79	1980–1989	1990–1999	2000–2009
Government administration and other infrastructures	24.53	22.87	25.47	26.21	22.68
Health infrastructures	11.44	9.27	10.07	9.16	15.99
Highways, roads, and bridges	36.22	41.25	38.09	37.39	31.47
Education infrastructures	14.08	15.76	11.34	15.50	16.25
Transit infrastructures	6.31	4.46	6.51	5.43	6.45
Waste, water and wastewater infrastructures	7.42	6.40	8.53	6.32	7.16
Total	100.00	100.00	100.00	100.00	100.00

Source: IAG and authors' calculations

Economic data, including gross domestic product (GDP), employment and private investment, are obtained from Statistics Canada.

Data for GDP in Ontario are from CANSIM Table 384-0002 and measured in millions of constant 2007 Canadian dollars. The original data series from Statistics Canada is presented in 2002 dollars. These were converted to 2007 values using the implicit GDP deflator from Statistics Canada. CANSIM Table 384-0002 extends from 1981 to 2010. Data from 1976 to 1980 and for 2011 are based on growth rates obtained from the Ontario Ministry of Infrastructures. This yields a series in growth rates that are identical to that implied by the data series in levels obtained from the Ontario Ministry of Infrastructures. Employment data are from CANSIM Table 282-0002 and measured in thousands of persons employed.

Private investment and public infrastructure investment data are from Table 031-0002 and are measured in millions of constant 2007 Canadian dollars. The private gross fixed capital formation is defined as the difference between total capital investments derived from this table and the public infrastructure investment data defined by the Ontario Ministry of Infrastructure as detailed below. It consists of investment in non-residential capital, including buildings, engineering, intellectual property products, and machinery, and equipment.

The data for public infrastructure investment are from the Investment Analytics Group of the Infrastructure Policy and Planning Division of the Ontario Ministry of Infrastructures based on data from Statistics Canada. It reflects important general trends in infrastructure investment over the past 50 years, namely growing infrastructure investment during the 1960s, a period not considered in our analysis, a subsequent slowdown in infrastructure investment during the 1970s, 1980s, and 1990s, and renewal in investment efforts since 2000. Indeed, public infrastructure investment was 4.3% of the GDP in the 1960s and declined to 2.6% during the 1980s and 1990s and has reached 2.8% in the past decade.

We consider six types of infrastructure investments. The first type is an investment in Government Administration and other infrastructures and includes investments in public administration buildings carried out by federal, provincial and territorial public administrations, and by local, municipal, and regional public administrations. It also includes a small residual component of public infrastructure investment. This category of infrastructure investment provides the foundations of law and order including the establishment and enforcement of property rights, and of the regulatory system in the economy. It represents 24.5% of total public infrastructure investment over the sample period and reached its maximum in the 1990s during which time it accounted for 26.2% of the total.

The second type is an investment in health infrastructures and includes fixed non-residential capital investment for ambulatory health-care services, hospitals, and nursing, and residential care

Table 3. VAR specification

Infrastructure Type	Model order	Deterministic components	Breaks
Government administration and other infrastructures	1	Constant and trend	1994, 1999
Health infrastructures	1	Constant and trend	1999
Highways, roads, and bridges	1	Constant and trend	1999, 2007
Education infrastructures	1	Constant and trend	1989, 1994, 1999
Transit infrastructures	1	Constant and trend	1999
Waste, water and wastewater infrastructures	1	Constant and trend	1989, 1999, 2002

VAR: Vector autoregressive

facilities. Investment in health-care infrastructures has a direct effect on the economy, through an increase in the provision of health-care services. In addition, the greater physical and psychological well-being of the population, while important in its own right, further reduces employee absenteeism and work disruptions and thereby provides for a more productive labor force. It represents 11.4% of public infrastructure investment and has seen a sharp increase in the past decade.

The third type is an investment in highways, roads, and bridges. Investment in highways, roads, and bridges has a direct positive effect on transportation services and, in general, as a positive externality by reducing travel time and the positive effects of road safety improvements. The impact on factor inputs is, in general, ambiguous. While it is possible that better highways will lead to greater employment and private investment, it is also possible that more highways mean more efficient transportation services which can be accommodated with better equipment and less personnel. It accounts for 36.2% of public infrastructure investment and peaked at 41.3% in the 1970s.

The fourth type is an investment in education infrastructures. It includes investment in fixed assets in elementary and secondary schools, community colleges, universities, business schools, and computer and management training centers, technical and trade schools, other schools and instruction, and educational support services. It has a direct impact on GDP through an increase in educational and training services. These investments also serve to provide for the integration of modern information and learning technologies in education. Better educational facilities lead in the longer term to a more educated, competent, sophisticated, and knowledgeable and thereby more productive labor force. Investment in educational facilities represents 14.1% of total infrastructure investment. It declined to an all-time low of 11.3% in the 1980s and rebounded there after.

The fifth type is an investment in transit infrastructures. It includes transit and other ground passenger transportation services. Investment in transit infrastructures directly affects the transportation industry and thereby GDP. It induces savings in travel time by alleviating congestion in highly trafficked areas and thereby liberates time for leisure and work activities. It represents increased accessibility of the population to markets thereby increasing economic activity. Investment in transit infrastructures increased sharply from 3.4% to 6.5% of total public infrastructure investment.

Finally, the sixth type is an investment in waste, water and wastewater infrastructures and includes water, sewage and other systems, and waste management and remediation services. Investment in waste, water and wastewater infrastructures directly affects output by increasing production in those sectors. The primary benefits of these environmental infrastructures are the resulting improvements in health, both directly through the water supply and indirectly through the amelioration of resulting environmental damages. It accounts for 7.4% of total public infrastructure investment.

Special attention was dedicated to the consideration of possible structural breaks reflecting fundamental changes in the Canadian or Ontarian economies. In this sense, dummies for 1989 (Canada-U.S. Free Trade Agreement), 1994 (North American Free Trade Agreement), 1999 (HIRF), 2002 (Ontario Strategic Infrastructure Financing Authority Act), and 2007 (the Great Recession) were included throughout the statistical analysis that follows when statistically relevant.

2.2. Univariate and cointegration analysis, and VAR specification

Table 3 presents the specification for the VAR model chosen based on the BIC. To determine the order of integration of the variables, we use the Augmented Dickey-Fuller (ADF) t-test to test the null hypotheses of a unit root. We use the Bayesian information criterion (BIC) to determine the optimal number of lagged differences to be included in the regressions, and we include deterministic components and structural breaks in the regressions if they are statistically significant. For all variables, the t-statistics are >5% critical values or at least the 1% critical values. Therefore, the ADF tests cannot reject the null hypotheses of a unit root of the variables in log-levels. Moreover, further ADF tests allow us to reject the null hypotheses of a unit root in the first differences of log levels for all of the variables at the 1% level of significance. This evidence suggests that all times series are stationary in first differences.

We also test for cointegration among the different variables. We perform these tests with each one of the six types of public infrastructure investment. Following the standard Engle-Granger approach, we perform four tests in each case. This is because it is possible that one of the variables will enter the cointegrating relationship with a statistically insignificant coefficient. We do not know, a priori, whether or not this will happen. If it does happen, however, a test that uses such a variable as the endogenous variable will not pick up the cointegration. Therefore, a different variable is endogenous in each of the four tests. We apply the ADF t-test to the residuals from the regressions of each variable on the remaining variables. In all of the tests, the optimal lag structure is chosen using the BIC, and deterministic components and structural breaks are included if statistically significant. For all six public investment variables, the values of the t-statistics are >5% critical values for at least three of the four cases considered. Moreover, the test statistics are larger than the 1% critical values in five of the 6 times in which they are <5% critical values. Thus, the ADF tests cannot reject the null hypotheses of a random walk, and we cannot reject that the variables are not cointegrated.

We have now determined that all of the variables have the same order of integration - they are all stationary of the first order. We have also determined that they are not cointegrated. Therefore, we estimate six VAR models, one for each of the six different types of public infrastructure investment. Given the non-stationary of the variables, we follow the standard procedure in the literature and determine the specifications of the VAR models using first differences of log levels, i.e., growth rates of the original variables. The specifications of the VAR models are determined using Log-Likelihood tests. In all cases, log-Likelihood tests suggest the first-order specification with a constant and a linear trend term and dummies for the five possible structural breaks introduced before.

3. Identifying and measuring the effects of innovations in public investment

In this section, we discuss the strategy for identifying innovations in public infrastructure investment as well as the different indicators used to measure the effects of these innovations on the economic variables. Once again, although details statistical results in this section are omitted in this paper, they are readily available from the authors on request.

3.1. Identifying the effects of innovations in public infrastructure investment

The core issue for the determination of the effects of public investment on economic performance is the identification of innovations in public infrastructure investment that is not contemporaneously correlated with innovations in the economic variables, that is, that are not subject to problems of reverse causality. In dealing with this issue, we draw from the approach typically followed in the literature on the effects of monetary policy (for example, Christiano, *et al*. (1996, 1998) and Rudebusch (1998)) and adopted by Pereira (2000) in the context of the analysis of the effects of public infrastructure investment.

Ideally, the identification of shocks to public infrastructure investment which is uncorrelated with shocks in other variables would result from knowing what fraction of the government appropriations in each period is due to purely non-economic reasons. The econometric counterpart to this idea is to consider a public policy function which relates the rate of growth of the public infrastructure investment to the relevant information set for the public sector; in our case, observations of the growth rates of the economic variables. The residuals from this policy function reflect the unexpected component to the evolution of infrastructure investment and are uncorrelated with other innovations.

In the central case, we assume that the relevant information set includes past values but not the current values of the economic variables. This is equivalent in the context of the standard Choleski decomposition to assuming that innovations in public investment lead innovations in economic variables. This means that while innovations in public infrastructure investment affect the economic variables contemporaneously, the reverse is not true. We have two reasons for making this our central case. First, it seems reasonable to believe that the economy reacts within a year to innovations in public infrastructure investment decisions. Second, it also seems reasonable to assume that the public sector is unable to adjust public infrastructure investment decisions to innovations in the economic variables within a year. This is due to the time lags involved in information gathering and public decision-making.

The estimated policy functions for the different types of public infrastructure investment relate the evolution of the respective public investments to the evolution of the economic variables with a 1-year lag. In no case were variables lagged more than one period statistically significant. More importantly, in no case were the contemporary values of the economic variables statistically significant. This confirms that our central case is the most plausible also from an econometric perspective. The fact that the matrix of variance-covariance among the estimated VAR residuals shows in all cases a block-diagonal pattern were innovations in public infrastructure investment show very low correlations with innovation in the economic variables, further confirms this strategy.

3.2. Measuring the effects of innovations in public infrastructure investment

We consider the effects of a 1 time, 1% point innovation in the rates of growth of the different types of public infrastructure investment on private investment, employment, and output. We expect these temporary shocks in the growth rates of the different types of public investment to have temporary effects on the growth rates of the other variables. They will, however, have permanent effects on the levels of these variables.

These effects are captured through the accumulated impulse response functions associated with the estimated VAR models. These accumulated impulse response functions are calculated with the corresponding 80% standard deviation bands. In all cases, we observe that the accumulated response functions converge smoothly and within a 5 years period. Furthermore, the standard deviation bands, which are significantly more stringent than normally used in the literature, are relatively narrow and confirm the significance of the estimated effects. In three cases, however, - the output effect of Government Administration and Other Infrastructures and the employment effect of investments in Education Infrastructure and waste, water, and wastewater infrastructures - the effects are not significantly different from zero.

To measure the effects of public infrastructure investment, we calculate the long-term elasticities and marginal products of the different economic variables with respect to each type of public infrastructure investment. The estimates under our central orthogonalization strategy, the

Table 4. Elasticities with respect to public infrastructure investment in ontario

Infrastructure Type	Private investment	Employment	Output
Government administration and other infrastructures	0.5030 (0.1495, 0.5030)	0.0224 (−0.0336, 0.0224)	0.0011 (−0.0525, 0.0011)
Health infrastructures	0.0484 (−0.1683, 0.1674)	0.0423 (−0.0066, 0.0644)	0.1132 (0.0019, 0.1408)
Highways, roads, and bridges	0.2065 (−0.0959, 0.2065)	−0.0441 (−0.0778, −0.0441)	−0.0382 (−0.1283, −0.0382)
Education infrastructures	0.0568 (0.0358, 0.1244)	0.0026 (−0.0029, 0.0191)	0.0683 (0.0209, 0.0745)
Transit infrastructures	0.0585 (0.0585, 0.1239)	0.0218 (0.0218, 0.0348)	0.0677 (0.0664, 0.0775)
Waste, water and wastewater infrastructures	0.1680 (0.1680, 0.2449)	0.0046 (0.0046, 0.0262)	0.0191 (0.0191, 0.0452)

In parenthesis are the ranges of variation for all possible orthogonalization strategies, which is equivalent to considering all the possible orderings of the variables within the Choleski decomposition framework

Table 5. Marginal products with respect to public infrastructure investment in ontario

Infrastructure Type	Private investment	Employment	Output
Government administration and other infrastructures	6.98 (2.08, 6.98)	35.75 (−53.55, 35.75)	0.16 (−7.34, 0.16)
Health infrastructures	0.99 (−3.46, 3.44)	99.85 (−15.64, 152.24)	23.46 (0.39, 29.2)
Highways, roads, and bridges	2.02 (−0.94, 2.02)	−49.70 (−87.62, −49.7)	−3.78 (−12.68, −3.78)
Education infrastructures	1.17 (0.74, 2.56)	6.22 (−6.84, 45.01)	14.17 (4.34, 15.44)
Transit infrastructures	2.50 (2.50, 5.30)	106.94 (106.94, 170.84)	29.19 (28.62, 33.43)
Waste, water and wastewater infrastructures	7.22 (7.22, 10.53)	22.71 (22.71, 129.28)	8.29 (8.29, 19.59)

In parenthesis are the ranges of variation for all possible orthogonalization strategies, which is equivalent to considering all the possible orderings of the variables within the Choleski decomposition framework

most plausible both conceptually and empirically, are presented in Tables 4 and 5. These tables also report in parenthesis the ranges of variation for all orthogonalization strategies, or what is equivalent, for all orderings of the variables under the Choleski decomposition, regardless of their plausibility.

The long-term elasticities measure the total percentage point changes in the economic variables for a long-term accumulated percentage point change in public infrastructure investment once all the dynamic feedback effects among the different variables have been considered. In turn, the long-term accumulated marginal products of public infrastructure investment measure the dollar changes in the economic variables per dollar of accumulated change in public infrastructure investment. We obtain them by multiplying the ratio of the economic variable to public infrastructure investment, for the past 10 years, by the elasticity of that variable with respect to public infrastructure investment. The choice of ratios for the past 10 years reflects the relative scarcity of different infrastructure investments at the margin of the sample period without letting these ratios be overly affected by business cycle factors.

Finally, the annual rates of return, reported in Table 6, are calculated from the marginal product figures by assuming a useful life schedule for each type of public capital asset consistent with its

Table 6. Rates of return on public infrastructure investment in Ontario

Infrastructure Type	Lifespan of years			
	20 (%)	30 (%)	40 (%)	50 (%)
Government administration and other infrastructures	-	-	-	-
Health infrastructures	17.1	11.1	8.2	6.5
Highways, roads, and bridges	-	-	-	-
Education infrastructures	14.2	9.2	6.9	5.4
Transit infrastructures	18.4	11.9	8.8	7.0
Waste, water and wastewater infrastructures	11.2	7.3	5.4	4.3

observed implicit depreciation rate. The rate of return is the annual rate at which an investment of one dollar would grow over the lifetime of the asset to yield its accumulated marginal product. The lifetime of each type of infrastructure is defined by a linear depreciation of the stock. This time period typically spans an average of 20 or 30 years and, in some instances, 50 years.

It should be noted that we use the terms elasticities and marginal products in a way that departs from the conventional definitions in most of the literature. In this research, the terms include all of the dynamic feedbacks among the variables. Therefore, these are total and not *Ceteris paribus* effects. That is, they measure both the direct dynamic effects of infrastructure investment on the economic variables and the indirect dynamic effects through changes in the evolution of employment and private investment. Of course, these are the relevant concepts from the standpoint of policymaking.

4. Public infrastructure investment and economic performance in Ontario

In this section, we present and discuss the estimates for elasticities and marginal products for the different types of infrastructure assets and provide some international comparisons.

4.1. Elasticities with respect to public infrastructure investment

The effects of shocks to the different types of public infrastructure investment on private investment are all positive. The strongest effect comes from a shock to investment in government administration and other infrastructures with an elasticity of 0.50. The weakest effect comes from a shock to health infrastructures with an elasticity of 0.05. In turn, in five of the six cases, the employment elasticities are positive. The strongest effect comes from shocks to investment in health infrastructures with an elasticity of 0.04. The negative effect comes from shocks to investment in highways, roads, and bridges and is −0.04.

The effects of shocks to investments on the different types of public infrastructures on output are positive, with the exception of investment in highways, roads, and bridges, which is negative and investment in government administration and other infrastructures, which is rather small, in fact, not statistically different from zero. The strongest effect comes from a shock to health infrastructures with an elasticity of 0.11. This is followed by the effect of education infrastructures (0.07), transit infrastructures (0.07), and waste, water, and wastewater infrastructures (0.02).

It is important to highlight the importance of considering both the direct and indirect effects of innovations in public investment. In fact, innovations in public investment on health infrastructures, which have the strongest effects on output, also have among the strongest effects on both employment and investment. This is consistent with the channels through which improved health care contribute toward labor productivity and growth. In turn, innovations in infrastructure investment in highways, roads, and bridges which yield a negative effect on output, have also a negative effect on employment.

The effects of public infrastructure investment on labor productivity can be obtained from the values of the elasticities as the change in the output to labor ratio is, by definition, the same as that of the difference between the elasticities of output and employment. We find that in general, the elasticity of output is much larger than the elasticity of labor which implies that public investment in infrastructures leads to a great increase in labor productivity. This is the case with health infrastructures and education infrastructures for which the induced increase in labor productivity is particularly strong and to a lesser extent, for transit infrastructures. The case of government administration and other infrastructures is the exception in that it actually leads to a decline in labor productivity.

4.2. The marginal products of public infrastructure investment

We now turn our attention to the marginal product of private investment, employment, and output with respect to each type of public infrastructure category. The marginal product figures are a better measure of the relative effects of different types of public infrastructure investments and the relevant measure from a policy perspective. This is because they reflect the relative scarcity of the different types of public investment at the margin of the sample period.

All types of infrastructure investment have a positive impact on private investment activities. Investment in waste, water and wastewater infrastructures has the largest positive effect on private investment, with a marginal product of $7.2, followed closely by investment in government administration and other infrastructures with a marginal product of $7.0. Much smaller effects are estimated for investment in transit infrastructures ($2.5), highways ($2.0), and in particular, education ($1.2), and health ($1.0).

All types of infrastructure investment have a positive impact on employment with the exception of investment in highways, roads, and bridges. The largest benefits come from investment in transit infrastructures which yield, over the long term, 107 permanent job posts per million dollars in investment. This is closely followed by health infrastructures with 100 permanent jobs. Investment in government administration and other infrastructures (36) shows more moderate effects while the effects from investment in education infrastructures and waste, water and wastewater infrastructures are not statistically different from zero.

Finally, in terms of their effects on output, the marginal product figures suggest that all types of public investment are productive, with the exception of investment in highways, roads, and bridges. Investments in transit infrastructures and health infrastructures have the largest positive impact on output with marginal products of $29.1 and $23.5, respectively. Investments in Education Infrastructures ($14.2) and Waste, Water and Wastewater Infrastructures ($8.3) also have a fairly strong positive effect on output. It should be noted that the corresponding rates of return for investments in these assets, assuming asset lifespans of 30 years, are 11.9%, 11.1%, 9.2%, and 7.3%, respectively. In contrast, investment in government administration and other infrastructures has a marginal product which is not statistically different from zero and investment in highways, roads, and bridges has a negative marginal product.

The negative effects of infrastructure investment on highways, roads, and bridges in Ontario deserve some considerations to help contextualization. We should start by noting that the effect although negative is small. Furthermore, the impulse response functions show clearly that the total negative effect is due to a negative effect on impact followed by a positive effect in subsequent periods. This suggests that construction itself leads to undesirable negative externality effects, traffic disruptions, for example, although the infrastructure itself when in place yields positive smaller effects. Overall, this is an indication of a very mature network that has reached a relatively low level of scarcity as it is widely recognized. As discussed below, this pattern of effects has been identified as well in some of the adjacent US states.

4.3. International comparisons

We focus here on comparisons with estimates of the effects of infrastructure investment in the United States, Portugal, and Spain based on the same methodological approach and therefore more directly comparable (for example, Pereira and Andraz (2013) for a survey of the more recent international evidence on the effects of public infrastructure investment). The United States provides for a comparison with an economy at a similar level of development and with similar levels of infrastructure scarcity as Ontario. In contrast, Portugal and Spain provide for comparison at a much greater level of scarcity in the infrastructure stock. Comparisons with the results for Portugal and Spain are more limited in that these cases only consider transportation infrastructure - roads, highways, ports, airports, and rail. In all cases, the data sets end in the middle the to late 1990s. The studies for the U.S. (Pereira (2000), Pereira and Andraz (2004, 2012)) use data from 1956 to 1997 while the Portuguese case (Pereira and Andraz (2005, 2006)) uses info from 1978 to 1998 and the Spanish case (Pereira and Roca (1999, 2003)) from to 1970 to 1995.

We begin by comparing the results obtained here for Ontario with the results in Pereira (2000) for the United States. Investment in government administration, health, and education is grouped together, and the estimated elasticities for output, employment, and private investment in the U.S. are 0.017, 0.003, and 0.022, respectively. These results are in line with our estimates for the output elasticity for general administration and other infrastructures, the elasticity of employment for education infrastructures, and the elasticity of private investment for health infrastructures, and educational infrastructures. This also suggests that our disaggregation is meaningful in that the three types of infrastructures yield considerably different results.

In turn, for transit infrastructure, the estimates for the U.S. are 0.213 (with a marginal product of \$19.8), 0.011, and 0.095 for output, employment, and private investment, respectively. The corresponding values for Ontario are 0.068 (with a marginal product of \$29.2), 0.022, and 0.059 and are of the same order of magnitude. In particular, the output effects are the largest of any of the infrastructure types in both the U.S. and Ontario cases.

Finally, for the U.S. the elasticities for waste and water management are 0.008 (with a marginal product of \$6.4), −0.012, and 0.012, with respect to output, employment, and private investment. For Ontario, all of the estimated elasticities are positive with an output elasticity of 0.019 (and a marginal product of \$8.3).

The case of the effects of investment in highways is very interesting. For the U.S., we estimate a positive but rather low elasticity of output of 0.006 with a marginal product of \$1.9. The elasticity of employment is negative, −0.006, and the elasticity with respect to private investment is 0.012. For Ontario, we also estimate a negative effect on employment and positive on investment. The effect on output, however, is negative. This is consistent with the very small effects identified in the U.S. case, indeed, the smallest effects among all infrastructure types in that study.

The results found here for Ontario are also consistent with evidence found for U.S. states which border the province found in Pereira and Andraz (2004, 2012). In this context, regional spillovers are particularly important. When considering the impact of highway investment within individual states, Michigan, New York, and Wisconsin each registered negative effects of highway investment while the estimated effects of highway infrastructure investment in Ohio ($1.23), Pennsylvania ($0.58), and Minnesota ($0.44) were all very small but positive. Furthermore, results for both New York and Wisconsin suggest a negative impact on private sector inputs, employment, and investment.

Pereira and Andraz (2004, 2012) also show that the state-specific results can only capture the full effects observed at the aggregate level for the U.S. if for each state we consider both investment in and out of the state - a network effects. In fact, spillovers account for nearly two-thirds of the overall economic impact of investment in highways. The general point is that given the nature of this infrastructure it is likely necessary to look at the overall pattern of investments in the surrounding provinces and U.S. states - network effects seem to be of the utmost importance. In the context of the US states neighboring Ontario, when regional spillovers are accounted for, the general effects of highway investment on output are much more significant, though these positive spillover effects are not large enough to reverse the overall negative impact observed in Michigan, New York, and Wisconsin.

Let's consider now how the results for Ontario compare to the results for Portugal and Spain. For transportation infrastructures in Portugal, Pereira and Andraz (2005, 2006) report long-term effects of €8.1 on private investment and 230 new jobs per million euros in public investment and a marginal product of €9.5 per euro of public investment. The corresponding marginal products for highway and road infrastructures in Portugal are €18.1, 25, and €8.4, for output, employment, and investment, which are substantially larger than the ones obtained for the U.S. and Ontario. For railroads, the figures are €18.5, 204, and €18.8, which are in line with our estimates for transit.

In turn, Pereira and Roca-Sagales (1999, 2003) consider the effects of public capital in transportation infrastructures in Spain. The empirical results suggest a marginal product of private investment with respect to the public investment of €10.2 and that one million euros in public investment create 129 jobs in the long-term. Moreover, the results indicate that the marginal product of public investment in Spain is €5.5.

Clearly the results for Spain and Portugal tend to be substantially higher than those for Ontario. This is understandable given the relatively greater scarcity of infrastructures in these countries and the fact that much of their public investment was financed by EU funds, thereby avoiding potential negative effects on the economy associated with domestic financing.

5. Summary and concluding remarks

This study analyzes the effects of public infrastructure investment on economic performance in Ontario, Canada. We employ a VAR approach to estimating the elasticity and marginal product of public infrastructure investment on private investment, employment, and output. This approach is consistent with the argument that the analysis of the effects of public infrastructure investment on economic variables requires the consideration of dynamic feedback effects among the different variables.

We find that all types of public investment crowd in private investment while investment in highways, roads, and bridges crowds out employment. We also find that all types of public investment, with the exception of highways, roads, and bridges, have a positive effect on output. Infrastructure investment in transit systems and health facilities display the highest returns. They are closely followed by public investment in educational facilities and waste, water and wastewater.

The range of results estimated for the impact of each of the different public infrastructure types is rather large. This suggests that an approach to the design of infrastructure investment policy that considers specific assets, as opposed to just general indiscriminate investment efforts, is required. In particular, some types of infrastructure may be better suited than others to address different specific policy objectives. If the objective is to promote private investment opportunities, the emphasis should be on investment in waste, water and wastewater infrastructures and investment in government administration and other infrastructures. If the objective is to promote employment, then investments in health infrastructures and transit infrastructures are the dominant strategic areas. In turn, if the objective is to promote output, the areas to stress are investments in health infrastructures and transit infrastructures and, to a lesser extent, education infrastructures. Finally, if the objective is to increase labor productivity, the best avenues are investments in health and education infrastructures and to a lesser extent on transit infrastructures.

In terms of the nature of the empirical results presented here, it would be important to highlight the fact that investments in health infrastructures, as well as investments in education infrastructures, are of great relevance. This is a pattern consistent with the mounting international evidence of the importance of human capital for long-term economic performance. On the flip side is the fact that investment in new highways, roads, and bridges does not seem to be of the greatest importance.

Overall, these results open the door to several important avenues of research directly relevant for policy purposes, in particular, the determination of the effects of different types of infrastructure assets at a much greater level of detail, including the effects of infrastructure investment at the industry and regional level in and within Ontario. Consideration of the issue of cross-border infrastructure investment spillovers effects, that is, the analysis of the interaction between infrastructure investments in Ontario and the economic performance of neighboring provinces and vice versa, would be particularly important. This would allow, among other things, for a more comprehensive and informative analysis of the effects of highways, roads, and bridges for which international evidence suggests the presence of very significant spillovers.

References

Agenor P, Nabli MK and Yousef TM (2005). Public Infrastructure and Private Investment in the Middle East and North Africa. Policy Research Working Paper No. 3661. New York: World Bank. doi: 10.1596/1813-9450-3661.

Aschauer D (1989a). Is public expenditure productive? *Journal of Monetary Economics*, 23: 177-200. doi: 10.1016/0304-3932(89)90047-0.

Aschauer D (1989b). Does public capital crowd out private capital? *Journal of Monetary Economics*, 24: 171-188. doi: 10.1016/0304-3932(89)90002-0.

Batina RG (1998). On the long-run effects of public capital and disaggregated public capital on aggregate output. *International Tax and Public Finance*, 5: 263-81. doi: 10.1023/A:1008626025932.

Belloc M and Vertova P (2006). Public investment and economic performance in highly indebted poor countries: An empirical assessment. *International Review of Applied Economics*, 20: 151-170. doi: 10.1080/02692170600581086.

Christiano L, Eichenbaum M and Evans C (1996). The effects of monetary policy shocks: Evidence from the flow of funds. *Review of Economics and Statistics,* 78(1): 16-34. doi: 10.2307/2109845.

Christiano L, Eichenbaum M and Evans C (1998). Monetary Policy Shocks: What Have we Learned and to What End? NBER Working Paper 6400. doi: 10.3386/w6400.

De Frutos RF, Garcia-Diez M and Perez-Amaral T. (1998). Public capital and economic growth: An analysis of the Spanish economy. *Applied Economics*, 30(8): 985-994. doi: 10.1080/000368498325156.

Demetriades P and Mamuneas T (2000). Intertemporal output and employment effects of public infrastructure capital: Evidence from 12 OECD economies. *Economic Journa*l, 110: 687-712. doi: 10.1111/1468-0297.00561.

Ghali KH (1998). Public investment and private capital formation in a vector error-correction model of growth.

Applied Economics, 30: 837-844. doi: 10.1080/000368498325543.
Gramlich E (1994). Infrastructure investment: A review essay. *Journal of Economic Literature,* 32: 1176-1196. Available from: http://www.jstor.org/stable/2728606.
Henckel T and McKibbin W (2017). The economics of infrastructure in a globalized world: Issues, lessons and future challenges. *Journal of Infrastructure and Policy Development*, 1(2): 254-271. doi: 10.24294/jipd.v1i2.55.
Kamps C (2005). The dynamic effects of public capital: VAR evidence for 22 OECD countries. *International Tax and Public Finance*, 12: 533-558. doi: 10.1007/s10797-005-1780-1.
Klein M (2017). Infrastructure policy: Basic design options. *Journal of Infrastructure, Policy and Development*, 1(2): 216-234. doi: 10.x24294/jipd.v1i2.77.
Lau S and Sin C (1997). Public infrastructure and economic growth: Time series properties and evidence. *The Economic Record*, 73(221): 125-135. doi: 10.1111/j.1475-4932.1997.tb00986.x.
Ligthart J (2002). Public capital and output growth in Portugal: An empirical analysis. *European Review of Economics and Finance,* 1(2): 3-30. doi: 10.5089/9781451842777.001.
Mamatzakis E (1999). Testing for long run relationship between infrastructure and private capital productivity: A time series analysis for the Greek industry. *Applied Economics Letters,* 6(4): 243-246. doi: 10.1080/135048599353438.
Mittnik S and Newman T (2001). Dynamic effects of public investment: Vector autoregressive evidence from six industrialized countries. *Empirical Economics*, 26: 429-446. doi: 10.1007/s001810000064.
Ontario Ministry of Infrastructure. Historical Investment in Public Infrastructure: Technical Presentation.
Otto G and Voss G (2002). Public and private investment in the United States and Canada. *Economic Modelling*, 19(4): 641-664. doi: 10.1016/S0264-9993(00)00074-2.
Pereira A (2000). Is all public capital created equal? *Review of Economics and Statistics,* 82(3): 513-518. doi: 10.1162/rest.2000.82.3.513.
Pereira A (2001). Public capital formation and private investment: What crowds in what? *Public Finance Review*, 29(1): 3-25. doi: 10.1177/109114210102900101.
Pereira A and Andraz J (2003). On the impact of public investment on the performance of US industries. *Public Finance Review*, 31(1): 66-90. doi: 10.1177/1091142102239135.
Pereira A and Andraz J (2004). Public highway spending and state spillovers in the USA. *Applied Economics Letters,* 11(12): 785-788. doi: 10.1080/1350485042000254593.
Pereira A and Andraz J (2005). Public investment in transportation infrastructures and economic performance in Portugal. *Review of Development Economic*s, 9: 177-196. doi: 10.1111/j.1467-9361.2005.00271.x.
Pereira A and Andraz J (2006). Public investment and regional asymmetries in Portugal. *Annals of Regional Science,* 40(4): 803-817. doi: 10.1007/s00168-006-0066-6.
Pereira A and Andraz J (2012). On the regional incidence of highway investments in the U.S.A. *Annals of Regional Science,* 48(3): 819-838. doi: 10.1007/s00168-010-0409-1.
Pereira A and Andraz J (2013). On the economic effects of public infrastructure investment: A survey of the international evidence. *Journal of Economic Development,* 38(4): 1-37. doi: 10.1177/1091142102239135.
Pereira A and Flores R (1999). Public capital accumulation and private-sector performance in the U.S. *Journal of Urban Economics*, 46: 300-322. doi: 10.1006/juec.1998.2124.
Pereira A and Pereira R (2018). Are all infrastructure investments created equal? The case of Portugal. *Journal of Infrastructure, Policy and Development*, 2(1): 67-86. doi: 10.24294/jipd.v2i1.145.
Pereira A and Roca-Sagales O (1999). Public capital formation and regional development in Spain. *Review of Development Economics*, 3(3): 281-294. doi: 10.1111/1467-9361.00068.
Pereira A and Roca-Sagales O (2003). Spillover effects of public capital formation: Evidence from the Spanish regions. *Journal of Urban Economics*, 53: 238-256. doi: 10.1016/S0094-1190(02)00517-X.
Regan M (2017). Future direction for infrastructure research. *Journal of Infrastructure, Policy and Development*, 1(2): 272-279. doi: 10.24294/jipd.v1i2.87.
Romp W and de Haan J (2007). Public capital and economic growth: A critical survey. *Perspektiven der Wirtschaftspolitik*, 8: 6-52. doi: 10.1111/j.1468-2516.2007.00242.x.
Rudebusch GD (1998). Do measures of monetary policy in a VAR make sense? *International Economic Review*, 39(4): 907-931. doi: 10.2307/2527344; doi: 10.2307/2527346.
Statistics Canada (no date). Table 031-0002 Flows and Stocks of Fixed Non-Residential Capital, by NAICS) and Asset, Canada, Provinces and Territories Annual (dollars x 1,000,000). CANSIM (database). Available from:

https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3410016301.
Statistics Canada (no date). Table 282-0002 Labour Force Survey Estimates (LFS), by Sex and Detailed Age Group, Annual (persons). CANSIM (database). doi: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410001801.
Statistics Canada Tables 031-0002 Flows and Stocks of Fixed Non-Residential Capital, Table 282-0002 Labor Force Survey Estimates, and Table 384-0002 Gross Domestic Product. Available from: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3410016301; https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410001801; https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610031201.
Sturm J, Jacobs J and Grote P (1999). Output effects of infrastructure investment in the Netherlands, 1853-1913. Journal of Macroeconomics, 21(2): 355-380. doi: 10.1016/S0164-0704(99)00107-X.