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GTAP Annual Conference on Global Economic Analysis
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Infrastructure in CGE models: Alternative formulations, empirical evidence, and a new approach

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April 15, 2021

DRAFT – NOT FOR PUBLICATION – DO NOT QUOTE!

Prepared for the 24th Annual Conference on Global Economic Analysis
June 23-25, 2021.

Abstract

The econometric literature shows that, when complementary conditions have been satisfied, investments in physical infrastructure have made a major contribution to economic progress. Drawing on these findings and the endogenous growth literature, computable general equilibrium (CGE) models have been designed to simulate the impact of infrastructure investments. Against this background, this paper (a) reviews econometric analysis of the impact of infrastructure on economic growth and the infrastructure-related CGE literature: formulations used, values and sources of key parameters, and simulation results; and (b) drawing on (a), tests a new formulation based on the marginal productivity of infrastructure capital. The new approach is flexible, data-driven and has limited core-data requirements but can be extended to cover additional features (like investment efficiency, capital quality, and operations and maintenance (O&M) costs when additional information is available.

Keywords: Infrastructure, Public investment, Productivity, Computable General Equilibrium.

1. Introduction

The econometric literature shows that, when complementary conditions have been satisfied, investments in physical infrastructure have made a major contribution to economics progress. Drawing on these findings and the endogenous growth literature, CGE models have been designed to simulate the impact of infrastructure investments.

This paper (a) reviews recent econometric studies on the links between infrastructure capital (or government capital) and output;¹ (b) takes stock of and extracts lessons from the infrastructure CGE literature to date: formulations used, values and sources of key parameters, and simulation results; and (c) drawing on this experience, tests a new flexible formulation that, in its core form, has limited data needs but, if additional information is available, may be enriched along multiple dimensions.

In outline, the paper first reviews econometric findings (Section 2) and models (CGE and related) (Section 3), and then proposes the new formulation (Section 4) that is tested in an applied model (Section 5). The rest of this partial draft provides section contents/plans in summary form.

2. Econometric studies of the impact of infrastructure investments

A large econometric literature has tried to assess the impact of public investment in general and infrastructure investment in particular on GDP and other variables. Table 2.1 summarizes findings from a set of recent studies, all published between 2011 and 2020.

¹ In general, the term infrastructure capital is used in this draft. However, even if it may not influence model structure, empirically, it is important to specify which type of capital that is covered.

Table 2.1. Selected studies of the links between growth and public investment (total or limited to infrastructure)

Calderón et al. (2011)	Description	The authors draw on a large data set of infrastructure stocks covering 88 countries and spanning the years 1960-2000 and use a panel time-series approach to estimate a long-run aggregate production function relating GDP to human capital, physical capital, and a synthetic measure of infrastructure
	Main findings	The long-run elasticity of output with respect to an infrastructure index (which covers transportation, power, and telecommunications) ranges between 0.07 and 0.10. No sign of heterogeneity across countries. There is little evidence of long-run parameter heterogeneity across countries
Calderón and Servén (2014)	Description	This paper reviews recent theoretical and empirical literature on the effects of infrastructure development on growth and income distribution.
	Main findings	Overall, the literature finds positive effects of infrastructure development on income growth and, more tentatively, based on sketchy evidence, also on distributive equity.
		According to meta-regression analysis using data from studies based on public investment spending, mainly covering industrial covers, the average elasticity of output with respect to public capital is around 0.10 with wide heterogeneity.
		As evidenced by congestion, few infrastructure services are pure public goods, and they are also frequently excludable. Effects are complicated by network effects.
		Limited understanding of many issues related to infrastructure (role of quality, crowding-in, role of TFP channel, costs of infrastructure development).
Cavallo and Daude (2011)	Description	This paper analyzes the relationship between public and private investment in developing countries.
	Main findings	Drawing on data for a panel of 116 developing countries for the period 1980 and 2006, public investment has on average crowded out private investment but never completely, as a result of which it has still led to higher output. Crowding out tends to be dampened or even reversed in settings with strong institutions, openness to international trade and financial flows, reducing the role of domestic financing constraints. Infrastructure investments tend to be more productive, crowding in private investment. Project quality (enhanced by careful selection) is crucial.
Gupta et al. (2014)	Description	Drawing on data for a large number of developing countries for the period 1960-2009, the authors estimate private and public capital stocks with and without adjustments for investment efficiency for the latter; and Investigate the effect of adjusted public capital on growth using a Cobb-Douglas approach. The robustness of the results are tested.
	Main findings	Using data for 52 countries, the MPs of public capital for their preferred approach with and without adjustments for the efficiency of public investments are: (a) For all countries: 0.69 and 0.52, respectively; (b) For middle-income countries: 0.51 and 0.30, respectively; (c) For LICs: 0.80 and 0.65, respectively
Lowe et al. (2018)	Description	The authors compute the MPs for public and private capital for many countries at different income levels and estimate the deadweight losses from public and private capital misallocation.
	Main findings	Private capital MPs are close across countries, suggesting that allocation is also relatively efficient. Public capital MPs vary widely but tend to be higher than private capital MPs, suggesting that public investment tends to be too low. The deadweight loss from public capital misallocation across countries can be much larger than the one from private capital.
Miyamoto et al. (2020)	Description	This study analyzes the macroeconomic impact of public investment and explores how the relationships among public investment, economic activity, and fiscal indicators are modified by the strength of a country's infrastructure governance.
	Main findings	The analysis finds that the strength of a country's infrastructure governance plays a critical role in determining the macroeconomic effects of public investment.
Urrunaga and Aparicio (2012)	Description	This article econometrically estimates the relations between infrastructure and economic growth for Peru, using different estimators with panel data from the 24 regions of Peru for the period 1980-2009.
	Main findings	The results confirm that public infrastructures (roads, electricity and telecommunications) are important in explaining differences in regional output. Evidence is also found of significant differences in the repercussions of the different infrastructures on per capita GDP in each region related to quality differences.

While their detailed findings vary, our review of these and other studies suggests that the literature has produced the following general insights:

- Across most country contexts, investments that raise the level of public capital stocks have had a positive impact on GDP with the size of these GDP effects summarized by positive marginal products and elasticities.
- The strength or, in some context, even the presence of such a positive relationship depends on a set of intervening or contextual factors, including:
 - the efficiency of investments (the extent to which investment spending is translated into physical capital);
 - the relevance of this physical capital to the growth process (in this respect, investments in infrastructures like transportation, communications, and energy tend to be particularly compared to broader categories of public investment); and
 - the impact of public investment on private investment. The impact is likely to be more positive (stronger crowding in or more limited crowding out) if private producers are able to mobilize needed investment funding (most importantly domestic but also foreign) in response to profit opportunities driven by new investments; the factors that matter include the general business environment, financial sector development, trade policies, and how the government finances its investments.

As a result of data limitations and other factors (including methodological issues, such as the difficulty of establishing causality), the literature has only focused on macro aspects. It has rarely addressed the roles of contextual factors like the impact of government financing mechanisms, the roles of public versus private infrastructure (including public-private partnerships), operations and maintenance (O&M) costs, and complementary policies. The disaggregation of infrastructure has been very limited at best and often the analysis has lumped infrastructure investments together with other public investments.

3. Review of the treatment of infrastructure in CGE models

Relevant models (CGE and related) have used a variety of formulations to link infrastructure to production and in their treatment of contextual factors (like links between the government budget and infrastructure financing). The review in this section is focused on the direct production link, for simplicity abstracting from other features of value-added functions like factor nesting.

The most basic approach has involved augmenting the value-added function to include a variable representing a stock of public or infrastructure capital (in addition to labor, capital, and other factors), i.e., in stylized form for activity a :

$$VA_a = A_a K_a^\beta L_a^{1-\beta} K_g^{\alpha_a}$$

where VA , A , K , L , and K_g stand for value added, the efficiency term, sector-specific capital and labor employment, and the stock of infrastructure capital; the exponents are elasticities; and the index a refers to production activities (see for example Adam and Bevan 2006, p. 270; Buffie et al. 2012, p. 9). In this formulation, producers have constant returns to scale in the factors that are subject to their production decisions but increasing returns to scale if infrastructure capital is included. Only one type of infrastructure stock considered. It is a pure public good since it is not subject to congestion or user fees. The stock enters the value-added functions for all sectors (unless the potentially activity-specific elasticity α is set at zero for some sector a).

Extensions of this approach, many of which have been developed and implemented by Agénor and coauthors, have considered the roles of congestion, capital stock quality, investment efficiency (sometimes referred to as absorptive capacity).

Congestion (like traffic jams) results when the stock is not large enough to accommodate all demanders without some loss like waiting times or service interruptions. Different models developed by Agénor and coauthors have considered this, with reference to equation 3.1 replacing $K_g^{\alpha_a}$ by $(K_g/VATOT_{t-1}^\theta)^{\alpha_a}$, where $VATOT$ is total value-added (lagged by one period to avoid simultaneity), θ is a congestion elasticity (zero if no impact of congestion) (Agénor et al. 2005, pp. 10 and 12) or, alternatively, by $(K_g/\bar{K})^{\alpha_a}$ where \bar{K} is the aggregate private capital stock, also given in year t as it depends on previous investments and depreciation (Agénor 2011, p. 4). It is also straightforward to consider the role of infrastructure quality (with or without simultaneous consideration of congestion) by replacing K_g by $qual \cdot K_g$ where $qual$ may be exogenous (as in Agénor 2010, p. 934; and Agénor et al. 2005, pp. 10 and 12, in the latter using a nested CES function in) but potentially could be endogenized (for example depending on O&M).

While quality here refers to the capital stock, studies have also considered investment efficiency (also referred to as absorptive capacity), which enters the definition of the capital stock. For an example, see Pinto Moreira and Bayraktar (2008, pp. 528 and 530) who define the infrastructure stock in period t as $K_{g,t} = \varepsilon \cdot I_{g,t-1} + (1 - \delta)K_{g,t-1}$, where ε is the investment efficiency parameter (1 for the case of full efficiency), δ the depreciation rate, and I_g infrastructure investment. In many countries, investment efficiency is of crucial importance, a point that was brought to the fore by Pritchett (2000). Investment efficiency could also be endogenized, for example reflecting the notion that it becomes less efficient as its level approaches the size of the already existing capital stock (Kendrick and Taylor 1970, p. 455).

The above references all are focused on the level of the current stock of infrastructure capital. Alternatively, some studies have expressed value added as a function of growth in the infrastructure stocks. Examples include Boccanfuso et al. (2014) and Chitiga et al. (2016) who, in the above value-added function, replace $K_g^{\alpha_a}$ by $(K_{g,t}/K_{g,t-1})^{\alpha_a}$. However, while this formulation may yield plausible results if the capital stock grows smoothly over time across all

scenarios, differences between scenario results could easily become implausible if growth is not uniform over time and across scenarios.²

[This section will be expanded to discuss additional studies, the empirical basis for infrastructure-related data (elasticities, capital stocks, other data), and policy relevance.]

4. A new approach to infrastructure modeling

A major drawback of the most common formulations, based on capital stocks and elasticities, is that they require data on the initial stock, a data point that typically is estimated with great imprecision (on the basis of past investment spending and depreciation rates) and affects simulation results (via its impact on stock growth) for any empirical elasticity data. Moreover, the relevance of the aggregate of heterogeneous non-depreciated investment for the analysis that is done is dubious.

The starting point for the new approach is that, in simulations, the impact of infrastructure is typically assessed by comparing results for non-base scenarios with their investment trajectories to the results for a base scenario with a different investment trajectory. In this light, the new formulation assesses the impact of non-base investment scenarios by linking their investment-driven deviations in infrastructure capital stocks from the base to empirical data on the marginal product (MP) of infrastructure capital (through its impact on TFP).

For a given MP, the gains may be distributed across sectors based on data on how the investment in question influences different sectors (e.g., roads may primarily impact transportation services) and sectoral weights in the economy. Drawing on empirical data, this formulation may be extended to consider other factors like investment efficiency and the impact of stock changes on the need for O&M services.

[Section to be expanded with a mathematical statement of the new approach with different variants.]

5. Implementing the new approach in a stylized CGE model

The new formulation is here implemented in a recursive-dynamic CGE model that is applied to a low-income country database, starting from Cicowiez and Lofgren (2017). The treatment of

² For example, if scenarios A and B differ in that, for scenario A, the infrastructure stock grows strongly in year 2 and has zero growth in year 3 whereas, for scenario B, it declines in year 2 but grows slightly in year 3, then the productivity effect of infrastructure capital in year 3 would be more positive under scenario B even though the stock in question is lower. Montaud et al. (2019, pp. 15-16) have the same formulation except for that multiple infrastructure capital stocks enter multiplicatively. A similar remark can be made about models that, instead of capital stock growth, use investment growth, $(I_{g,t}/I_{g,t-1})^{\alpha_a}$ (Savard 2010, p. 46).

infrastructure is based on the new formulation presented in Section 4, including extensions to capital stock quality, investment efficiency, and O&M. Algebraically, the inclusion/exclusion of different features is data-driven, making it possible to use this formulation in a template model. The formulation will be tested via scenarios with positive and negative shocks and its results will be contrasted with results from the implementation of one or more alternative formulations, identified in Section 3.

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