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INTERNATIONAL ASPECTS OF PUBLIC INFRASTRUCTURE INVESTMENT*

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Abstract

Modelling infrastructure as an international public good in a two-country model of trade where each country's social planner behaves strategically, we show that the equilibrium levels of infrastructure are sub-optimal from a global perspective. Utilising an appropriate econometric framework and data from 14 countries over the period 1971-90, we find evidence that accords well with the main predictions of our theory. Thus, we are able to offer a plausible theoretical explanation why public capital may be under-supplied, as suggested by previous empirical literature.

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INTERNATIONAL ASPECTS OF PUBLIC INFRASTRUCTURE INVESTMENT

I Introduction

A central question in the empirical literature on infrastructure has been whether existing stocks of public capital are sub-optimal. While the initial estimates of David Aschauer (1989a, 1989b, 1989c), which places the rate of return of public capital in the US at around 60% per annum, have been questioned by subsequent literature[1], the debate on whether there is under-investment in infrastructure is far from settled. Even though some investigators have found negligible, or even negative, effects of public capital on private productivity (e.g. Evans and Karras, 1994, Holtz-Eakin, 1994), others have found positive effects (e.g. Nadiri and Mamuneas, 1994, Lynde and Richmond, 1992 and 1993, Berndt and Hansson, 1992), which in some cases suggest that there may be an under-supply of public capital (e.g. Morrison and Schwartz, 1996, Demetriades and Mamuneas, 1997).

In this paper we provide a theoretical explanation why public infrastructure may be under-supplied by exploring the international aspects of investment in public infrastructure. Our starting point is the observation that a large component of public infrastructure investment is devoted to the extension and upgrading of transport and communications networks, which reduces transport costs and facilitates trade of goods both *within* and *across* national borders. Thus, any investment in infrastructure by the domestic economy is likely to benefit not only domestic but also foreign producers and consumers. Similarly, any investment in infrastructure by a foreign country is likely to benefit domestic producers and consumers as long as the foreign country concerned has trading links with the domestic economy. Infrastructure, therefore, has characteristics of an international public good, which suggests that its provision may be subject to an international co-ordination problem.

While the link between transport costs and trade is commonplace in the trade literature[2], the idea that infrastructure might affect trade is a more recent one. The survey by Casas (1983) touches on it while Bougheas, Demetriades and Morgenroth (1997) provide a fuller analysis in a symmetric two-country model which examines the effects of infrastructure on specialisation and the volume of trade. The symmetric nature of their model, however, does not allow the authors to address co-ordination issues such as the question of how countries might share the cost of inftrastructure provision, which gives rise to the possibility of under-investment. It is precisely these issues which are the focus of the current paper.

Our theoretical approach involves constructing a simple general equilibrium two country - two good model in which infrastructure investment influences domestic and international trade by reducing transport costs[3]. We assume that domestic transport costs are country specific, varying inversely with domestic infrastructure, while international transport costs are common, varying inversely with the sum of the two countries' infrastructure. For example, it is reasonable to argue that if Britain improves its motorway network, this is likely to reduce the cost of transporting goods between Britain and France as well as the cost of transporting goods within Britain. Improving British motorways is, however, unlikely to reduce the cost of transporting goods within France.

[1] See Gamlich (1994) for an extensive review of the literature.
[2] See for example the classic references by Samuelson (1954) and Mundell (1957).
[3] Clarida and Findlay (1994), and Chiu (1997) develop trade models with public investment without focusing specifically on transport infrastructure and transport costs. Bond (1997) constructs a partial equilibrium model of trade with transport costs and examines trade policy issues.

Our method of solving for the equilibrium of the model applies the concept of *voluntary-contribution* (see Laffont, 1988) for finding the infrastructure investments by the two social planners while the two goods are traded in competitive markets[4]. Specifically, we assume that the two social planners behave strategically, allocating their endowment between production and investment in infrastructure taking as given the policy of the other planner and recognising the effect of their decision on the equilibrium price mechanism. The competitive market mechanism subsequently determines the allocation of consumption between the two goods. We examine the efficiency of the equilibrium by comparing it to the case where the two social planners behave co-operatively. This solution corresponds to the outcome which would be proposed by a "global" social planner.

We subject our theoretical model to rigorous empirical testing to examine its empirical relevance. Specifically, we construct an econometric model which captures all the important elements of the theoretical model and estimate it by simultaneous methods using aggregate data. Our empirical results are consistent with the theory. Importantly, the international strategic nature of public infrastructure investment is clearly supported by the evidence, suggesting that our theoretical explanation of the possibility of under-investment is a plausible one.

The paper is organised as follows. Section 2 puts forward the theoretical model and provides the equilibrium solution while section 3 examines efficiency aspects. Section 4 puts forward the econometric model, explains its linkages to the theory and discusses estimation methods. Section 5 describes the data used for estimation while section 6 presents the empirical results. Finally, section 7 summarises and concludes.

[4] Fisher and Mirman (1992), Datta (1997) and Mirman and Datta (1997) use the same approach to study dynamic externalities.

II The Model

There are two countries: the “home” country (H) and the “foreign” country (F); the latter can be thought of as representing the rest of the world. Each country produces only one good. H produces good h and F produces f. The agents of each country derive utility from consumption of both goods, hence there is trade. Each country is endowed with a capital good. Let z_H and z_F denote the endowment of H and F, respectively. Each unit of the capital good can produce one unit of the domestic good.

The endowments can also be used for the development of infrastructure which reduces transport costs which, in turn, influence domestic and international trade. Following Samuelson’s “iceberg” model (see Samuelson, 1954), we assume that only a fraction of the goods shipped arrive at their final destination. Let g denote the fraction of exports consumed. We further assume that the consumption of domestically produced goods is also subject to transport costs[5]. Let g_H and g_F denote the corresponding fractions. Notice that while domestic transport costs are country specific, international transport costs are common. Transport costs are endogenous and depend on the quality of public infrastructure. Without continuous improvement through additional investment, the existing stock of public infrastructure, i.e. road networks, telecommunications etc. will deteriorate and consequently transport costs will be high. Let z_{HG} and z_{FG} denote the investment in infrastructure of H and F, respectively. Then, the transport cost technologies are given by:

(1) $g_H = g_H(z_{HG})$

(2) $g_F = g_F(z_{FG})$

[5] Martin and Rogers (1995) in a model of industrial location also consider both types of transport costs.

(3) $g = g(z_{HG} + z_{FG})$

where $0 < g_H, g_F, g < 1$, $z_{HG} \leq z_H$, $z_{FG} \leq z_F$ and all the functions are strictly increasing and concave. Notice that any investment in infrastructure will affect both domestic and international transport costs. Furthermore, the two investments are perfect substitutes in the international technology. Perfect substitutability is only assumed for simplicity. As long as there is some substitutability the equilibrium level of infrastructure will, generally, be sub-optimal.

In this model there is a two-level decision making in each country. The allocation of the capital good between production and infrastructure investment is decided by a social planner. Afterwards, a competitive market decides the allocation of consumption between the two goods. We capture the trading process with a price taking, utility maximising, representative agent who takes the social planner's decision as given. Market clearing determines the equilibrium prices which depend on the decisions of both social planners. While agents behave competitively, the two social planners behave strategically. Each planner makes a decision, taking into account the equilibrium price mechanism, given the other social planner's decision.

Let c_{ij} $(i = H, F; j = h, f)$ denote the consumption of the representative agent in country i of good j. Preferences in each country are specified as follows:

(4) $U_i(c_{ih}, c_{if}) \equiv q_{ih} \log c_{ih} + q_{if} \log c_{if}$, $\qquad i = H, F$

With the above functional form we can get closed form solutions without imposing any further restrictions on the infrastructure technologies[6]. However, the analysis of Nash-Cournot equilibria in public goods games by Cornes and Sandler (1996) suggests that our results are robust to more general

[6] See also the discussion in the following section.

specifications. Our method of solution is as follows. The first step is to solve each representative agent's maximisation problem. Each agent takes prices, p_h and p_f, and his income, $y_i = z_i - z_{iG}$, as given. Notice that the income levels depend on the social planner's decision. The solution of these problems will express consumption allocations as a function of relative prices $\left(p \equiv p_f / p_h\right)$ and income. Using these solutions together with the two market clearing conditions we can express the relative price as a function of the two income levels. The next step is to substitute the above solutions in the preference functions and derive the indirect utility functions for each agent. Each social planner maximises the corresponding indirect utility function by choosing his country's investment in infrastructure and taking the other planner's decision as given. The solution of these problems will yield the two reaction functions which will determine the equilibrium investments in infrastructure by the two social planners.

The following program describes the utility maximisation problem of the representative agent of country H:

Max $q_{Hh} \log c_{Hh} + q_{Hf} \log c_{Hf}$,

subject to: $p_h \dfrac{c_{Hh}}{g_H} + p_f \dfrac{c_{Hf}}{g} = p_h y_H$

The solution is given by:

(5) $c_{Hh} = \dfrac{q_{Hh}}{q_{Hh} + q_{Hf}} g_H y_H$ and $c_{Hf} = \dfrac{q_{Hf}}{q_{Hh} + q_{Hf}} \dfrac{g}{p} y_H$

Because of the logarithmic specification the demand for each good is proportional to income (net of any infrastructure investment). The proportionality factor depends on how strong preferences are for the home good relative to the foreign good and on relative prices which depend on transport costs. Similarly, the corresponding program for country F yields the following solution:

(6) $c_{Ff} = \frac{q_{Ff}}{q_{Ff} + q_{Fh}} g_F y_F$ and $c_{Fh} = \frac{q_{Fh}}{q_{Ff} + q_{Fh}} gpy_F$

The equilibrium allocations must also satisfy the following feasibility constraints:

(7) $z_H - z_{HG} \geq \frac{c_{Hh}}{g_H} + \frac{c_{Fh}}{g}$

(8) $z_F - z_{FG} \geq \frac{c_{Ff}}{g_F} + \frac{c_{Hf}}{g}$

The left hand side of each expression is equal to the production of the domestic good which is also equal to income. The right hand side shows the allocation of production between domestic consumption and exports. The equilibrium relative price (terms of trade) is given by:

(9) $p = \frac{c_{Fh} / g}{c_{Hf} / g} = \frac{q_{Hf}\left(q_{Ff} + q_{Fh}\right)}{q_{Fh}\left(q_{Hh} + q_{Hf}\right)} \frac{z_H - z_{HG}}{z_F - z_{FG}}$

Because of the logarithmic preferences the amount that each country spends on each good is proportional to its income. In addition, because international transport costs are common, they do not enter directly into the equilibrium condition. However, transport costs, both domestic and international, affect indirectly the equilibrium price because they affect the allocations of the two social planners which determine the levels of income.

Using (5), (9), and the preferences of the representative agent of H, we can derive the corresponding indirect utility function. The social planner of H maximises this utility by choosing investment in infrastructure, z_{HG}, taking as given the investment of country F, z_{FG}:

$$V\left(z_{HG};z_H,z_F,z_{FG}\right) \equiv Max \;\; q_{Hh} \log g_H\left(z_{HG}\right) + q_{Hh} \log\left(z_H - z_{HG}\right)$$
$$+ q_{Hf} \log g\left(z_{HG} + z_{FG}\right) + q_{Hf} \log\left(z_F - z_{FG}\right) + \text{constant}$$

The solution of the above problem yields the following reaction function:

$$(10) \quad q_{Hh} \frac{1}{z_H - z_{HG}} = q_{Hh} \frac{g'_H\left(z_{HG}\right)}{g_H\left(z_{HG}\right)} + q_{Hf} \frac{g'\left(z_{HG} + z_{FG}\right)}{g\left(z_{HG} + z_{FG}\right)}$$

where primes denote the first derivatives. By multiplying both sides of the above equality by z_{HG} we find that the optimal policy requires that the ratio of the investment in infrastructure to production should be higher the more responsive the transport cost functions are to the former. By totally differentiating (10) we can show that the reaction function has a negative slope with an absolute value less than one. In addition, a higher endowment entails higher domestic investment in infrastructure for any level of investment by the other country.

The social planner of F faces a similar optimisation problem which yields the following reaction function:

$$(11) \quad q_{Ff} \frac{1}{z_F - z_{FG}} = q_{Ff} \frac{g'_F\left(z_{FG}\right)}{g_F\left(z_{FG}\right)} + q_{Fh} \frac{g'\left(z_{HG} + z_{FG}\right)}{g\left(z_{HG} + z_{FG}\right)}$$

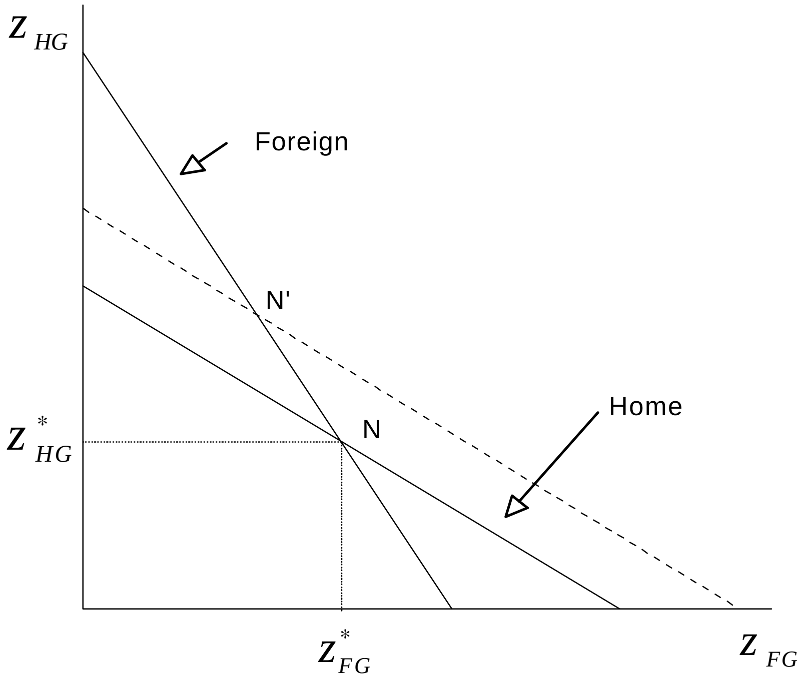
which has similar properties.

The unique Cournot-Nash equilibrium is found by the intersection of the two reaction functions. Figure 1 shows the equilibrium, N, of this economy. An increase in the 'home' endowment will shift the 'home' reaction function to the right. At the new equilibrium, N', the home country's investment in infrastructure increases while that of the foreign country decreases. In summary:

(12) $\frac{dz_{iG}}{dz_i} > 0$ and $\frac{dz_{iG}}{dz_j} < 0$; $i, g = H, F \quad i \neq j$.

Investment in infrastructure in both countries is increasing in their own endowment but decreasing in the other country's endowment.

Figure 1. Cournot – Nash equilibrium



III Efficiency

In this section we compare the non-co-operative solution found in the previous section to the co-operative outcome. In the co-operative case, we choose the investment levels in the two countries, (z_{HG}, z_{FG}), and the levels of consumption, $(c_{Hh}, c_{Hf}, c_{Ff}, c_{Fh})$, to maximise the sum of utilities subject to the two feasibility constraints. This solution is Pareto optimal and corresponds to the case where the utilities are equally weighted. Formally:

Max $q_{Hh}\log c_{Hh} + q_{Hf}\log c_{Hf} + q_{Ff}\log c_{Ff} + q_{Fh}\log c_{Fh}$

subject to (7) and (8).

Let l_1 and l_2 denote the Lagrangean multipliers which correspond to the constraints (7) and (8), respectively. Then the first order conditions of the above problem are:

(13) $\frac{q_{Hh}}{c_{Hh}} = \frac{l_1}{g_H}$

(14) $\frac{q_{Hf}}{c_{Hf}} = \frac{l_2}{g}$

(15) $\frac{q_{Ff}}{c_{Ff}} = \frac{l_2}{g_F}$

(16) $\frac{q_{Fh}}{c_{Fh}} = \frac{l_1}{g}$

(17) $-l_1 + l_1 c_{Hh}\frac{g'_H}{g_H^2} + l_1 c_{Fh}\frac{g'}{g^2} + l_2 c_{Hf}\frac{g'}{g^2} = 0$

(18) $$-l_2 + l_2 c_{Ff} \frac{g'_F}{g_F^2} + l_2 c_{Hf} \frac{g'}{g^2} + l_1 c_{Fh} \frac{g'}{g^2} = 0$$

Using (7), (13) and (16), we get:

(19) $c_{Hh} = \dfrac{q_{Hh}}{q_{Hh} + q_{Fh}} g_H\left(z_H - z_{HG}\right)$ and $c_{Fh} = \dfrac{q_{Fh}}{q_{Hh} + q_{Fh}} g\left(z_H - z_{HG}\right)$

Using (8), (14), and (15), we get:

(20) $c_{Ff} = \dfrac{q_{Ff}}{q_{Ff} + q_{Hf}} g_F\left(z_F - z_{FG}\right)$ and $c_{Hf} = \dfrac{q_{Hf}}{q_{Ff} + q_{Hf}} g\left(z_F - z_{FG}\right)$

From (14) and (16), we get:

(21) $$\frac{l_2}{l_1} = \frac{q_{Hf}}{q_{Fh}} \frac{c_{Fh}}{c_{Hf}}$$

Substituting (19) and (21) in (17) and rearranging, we get:

(22) $$\frac{q_{Hh} + q_{Fh}}{z_H - z_{HG}} = q_{Hh} \frac{g'_H\left(z_{HG}\right)}{g_H\left(z_{HG}\right)} + \left(q_{Hf} + q_{Fh}\right) \frac{g'\left(z_{HG} + z_{FG}\right)}{g\left(z_{HG} + z_{FG}\right)}$$

Similarly, substituting (20) and (21) in (18), we get:

(23) $$\frac{q_{Ff} + q_{Hf}}{z_F - z_{FG}} = q_{Ff} \frac{g'_F\left(z_{FG}\right)}{g_F\left(z_{FG}\right)} + \left(q_{Hf} + q_{Fh}\right) \frac{g'\left(z_{HG} + z_{FG}\right)}{g\left(z_{HG} + z_{FG}\right)}$$

Equations (22) and (23) jointly determine the co-operative solution for investment in infrastructure by the two countries. Next, we compare these solutions with the two reaction functions, (10) and (11). Without loss of generality, we impose the following restriction:

Assumption 1: $q_{Hh} + q_{Hf} = q_{Ff} + q_{Fh} = 1$ (Monotonic Transformation).

Given the logarithmic specification and the above restriction q_{ij} represents the fraction of its net income $\left(z_i - z_{iG}\right)$ that country i spends on the good produced by country j.

Since the solutions for the two countries are symmetric, we concentrate on (22) and (10), the solution for the home country. The difference is the term q_{Fh} which appears in the numerator of the left-hand side and the numerator of the second term of the right-hand side of the co-operative solution. Let us examine these terms more closely.

The left-hand side captures the marginal cost of infrastructure investment. An increase in infrastructure investment by one unit reduces the amount available for consumption by one unit. The social planner of H takes into account that home consumption is only reduced by a fraction q_{Hh}, while for the global optimum we need to take into account the corresponding reduction in the utility of the foreign country's representative agent. The term q_{Fh} appears in the co-operative solution because it represents the fraction of its income that the foreign country spends on the home good. Therefore, the social planner of H underestimates the marginal cost of infrastructure investment, which leads to *over-investment*.

The second term of the right-hand side captures the marginal benefits of infrastructure investment from the reduction in the international transport cost function. While the social planner of H takes into account only the benefits for country H, the social planner also considers the benefits for country F. This effect leads to *under-investment*.

Let $*$ denote the non-co-operative solutions. After subtracting (10) from (22), we arrive at the following result:

Proposition 1:

If $$q_{Fh}\left\{\frac{g'\left(z_{HG}^{*}+z_{FG}^{*}\right)}{g\left(z_{HG}^{*}+z_{FG}^{*}\right)}-\frac{1}{z_{H}-z_{HG}^{*}}\right\}>0$$

then there will be under-investment in infrastructure.

It is useful to examine the extent to which under-investment is likely using the above result. The first term in the parenthesis represents the difference between the marginal national benefits from the marginal global benefits of infrastructure investment. It captures the spill-out benefits of infrastructure investment and the stronger it is, the more likely that there will be under-investment. The second term captures the global cost of infrastructure investment and is probably overstated by the preference specification. Under logarithmic preferences the fraction of income that each country spends on each good is constant, as a result of which the terms of trade are equal to the ratio of incomes (for symmetric preferences)[7]. As one country increases its infrastructure investment, thus reducing its net income, it improves its terms of trade. While this reduces the amount of its own good available for trade, it does not affect the amount that it imports from abroad. This reflects the absence of price substitution, which is a peculiarity of the logarithmic utility function. The logarithmic specification was adopted because it allows for a closed-form solution. Under more plausible specifications, a change in the

[7] By symmetric preferences we mean that $q_{Hh} = q_{Ff}$ and $q_{Hf} = q_{Fh}$.

terms of trade will also induce a substitution effect which would weaken the strength of the second term[8].

IV Econometric Model

In order to test the predictions of our model we construct a simple econometric model that focuses on the long run effects of public investment. We adopt the convention that the 'foreign country' essentially represents the trading partners of the domestic economy. Since it is difficult to classify transport costs into domestic and international we restrict our analysis to modelling the effects of total transport costs. Nevertheless, our specification allows us to test some of the main predictions of our model, for example that increases in foreign income reduce domestic infrastructure investment, which is the result of the strategic interaction between international policy-makers.

The model is specified in log-linear form and consists of three equations which respectively determine infrastructure investment, total transport costs and total imports for each country. Infrastructure investment of country i, ZG_i, is related positively to that country's endowment as measured by its real GDP, Y_i, but negatively to i) the cost of investment, CI_i, which we proxy with the long term interest rate and ii) the sum of real GDP's of country i's trading partners, SY_j. Consistent with our theoretical model, transport costs for imports from all countries into country i, TC_i, are inversely related to both the domestic and the sum of all foreign infrastructure investment, ZG_i and SZG_j, and are increasing in the average distance between country i and all its trading partners, R_i. We define R_i as $R_i = \frac{1}{n}\sum D_{ij}$ where n is the number

[8] In a recent paper, Bond (1997), develops a partial equilibrium model which effectively eliminates the effect of infrastructure investments on the output of the two goods. Under the same conditions, our model clearly suggests that there will be under-investment in infrastructure.

of trading partners and D_{ij} is the distance between country i and trading partner j [9].

Finally, import demand in country i for goods from all its trading partners, M_i, is related positively to domestic income and negatively to transport costs. In most empirical studies the terms of trade and the exchange rate are also included (e.g. Thursby and Thursby, 1984, and Deyak, Sawyer and Sprinkle, 1993). However, if purchasing power parity holds, these would only matter in the short run. Since we are interested in the long-run effects of public investment we omit these variables[10].

The whole system can thus be written as follows:

(24) $ZG_i = a_z + b_{11}Y_i + b_{12}SY_j + b_{13}CI_i + e_Z$

(25) $TC_i = a_T + b_{24}ZG_i + b_{25}SZG_j + b_{26}R_i + e_T$

(26) $M_i = a_M + b_{31}Y_i + b_{37}TC_i + e_M$

Where e_Z, e_T and e_M are error terms which are assumed to be independently and identically distributed. This specification contains the implicit assumption that the coefficient on all the foreign infrastructure investments is equal which is somewhat restrictive. However this can be overcome if the components of the sum of foreign infrastructure are weighted according to the corresponding share of imports. Foreign public investment is assumed to be exogenous which is consistent with our theoretical model. However, since in the econometric specification foreign infrastructure investment is determined by foreign income this might introduce an

[9] A similar variable is used by Wei (1996).
[10] Preliminary results using these variables suggested they were in fact insignificant as expected.

endogeneity problem to our model. We therefore report results from estimations with and without the sum of foreign infrastructure investment.

This system could be estimated using methods such as Full Information Maximum Likelihood (FIML) or Three Stage Least Squares (3SLS). However, it is more convenient to write the above model as a reduced form which can then be estimated with more conventional methods. The full reduced form is as follows:

(27) $ZG_i = a_z + b_{11}Y_i + b_{12}SY_j + b_{13}CI_i + e_z$

(28) $TC_i = V_T + p_{21}Y_i + p_{22}SY_j + p_{23}CI_i + b_{25}SZG_j + b_{26}R_i + e_T$

(29) $M_{ij} = V_M + p_{31}Y_i + p_{32}SY_j + p_{33}CI_i + p_{35}SZG_j + p_{36}R_i + e_m$

where $V_T = a_T + b_{24}a_Z$, $p_{21} = b_{24}b_{11}$, $p_{22} = b_{24}b_{12}$, $p_{23} = b_{24}b_{13}$, $V_M = a_M + b_{37}V_T$, $p_{31} = b_{31} + b_{37}p_{21}$, $p_{32} = b_{37}p_{22}$, $p_{33} = b_{37}p_{23}$, $p_{35} = b_{37}b_{25}$, $p_{36} = b_{37}b_{26}$, $e_T = b_{24}e_Z + e_T$, and $e_M = b_{37}e_T + e_M$.

The main predictions of our model concerning the coefficients of the reduced form are that b_{11}, b_{26}, p_{22}, p_{23}, p_{31} and p_{35} should be positive while b_{12}, b_{13}, b_{25}, p_{21}, p_{32}, p_{33} and p_{36} should be negative. We attach particular importance on β_{12} in equation 1, the expected negative sign of which reflects the strategic nature of domestic infrastructure investment decisions. Note that if foreign infrastructure is assumed endogenous and dropped from equation (29), the sign of p_{32} might change since this coefficient will also capture the dependence of total foreign infrastructure on total foreign income, which is likely to be positive.

V Data

Our data consists of annual observations for the period from 1971 to 1990 covering 14 countries, namely Australia, Belgium/Luxembourg, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, the United Kingdom and the USA. The choice of countries was determined by the availability of infrastructure data.

Data for public investment in constant 1985 US dollars, which we use to proxy infrastructure investment, were obtained from the OECD Sectoral Database. Imports in current US dollars are freight on board (f.o.b.) and taken from the IMF Direction of Trade Statistics (DOTS) and are converted to constant 1985 US dollars using the US GDP deflator from the Penn World Tables (Mark 6). Real GDP in constant 1985 US dollars is also obtained from the Penn World Tables. Distance, as measured by the great circle distance between major cities, was obtained from Jon Haveman's international trade data, which can be downloaded from the Purdue University Internet site[11].

The long-run real interest rate was constructed by subtracting the change in the public investment deflator, which is taken from the OECD Sectoral Database, from the long run government bond yield which was taken from the IMF International Financial Statistics (IFS) data base[12].

Data for transport costs are not readily available. The difference between the imports of country i from country j, measured inclusive of freight costs and insurance (c.i.f.), and the freight on board exports from country j to i (f.o.b.) should be a good measure of transport costs. However, calculating transport costs in this manner, using the data from the IMF DOTS Database, produces

[11] The data can be downloaded from:
http://intrepid.mgmt.purdue.edu/Jon/Data/TradeData.html#Gravity

[12] For Japan the public investment deflator was not available and instead we use the GDP deflator. The government bond yields for the various countries are not available for the same length of maturity of the bond. However, the shortest length of maturity is ten years.

values that are sometimes negative. This suggests that the imports c.i.f. data may suffer from some under recording. This is quite plausible since the levying of import duties and taxes is usually based on c.i.f. values at the point of entry. Alternatively, this problem might point to some shortcomings in the methods of data collection employed to obtain this data. Similar shortcomings can be expected with the freight factor published by the IMF[13]. This variable is constructed by dividing total c.i.f. imports by total f.o.b. imports, thus yielding a measure of transport and insurance costs for imports. The freight factor in 1990 for the sample of countries used here ranged from 2% for Sweden to 9% for Japan which seem plausible. However, the series is almost constant for some countries and contains one observation where transport costs appear to be negative[14]. Given these problems, we drop equation (28) from the estimation.

In order to capture the long run effects of public investment and to eliminate cyclical effects, we average our data over four non-overlapping periods, 1971-74, 1975-79, 1980-84, 1985-90. Given that we are using total trade for each country we have 14 observations per period for the import equation. Similarly, since we use the sum of foreign incomes we are left with 14 observations per period for the infrastructure equation. In order to obtain a reasonable sample size for estimation all the observations are pooled yielding a sample of 56 observations.

VI Estimation and Results

The model (27) - (29) is clearly overidentified, but since we do not have reliable data for transport costs we can not estimate equation (28) and thus only some of the structural parameters can be identified. Despite the obvious

[13] A similar variable was constructed by Harrigan (1993).
[14] This observation is for the UK in 1974 where the factor is reported to be 0.92 implying that c.i.f. imports were 8% larger than f.o.b. imports.

shortcoming of having to drop equation (28), the general validity of our theoretical model can still be tested since our model makes specific predictions about the signs of various structural coefficients. Furthermore, we can still test one over-identifying restriction and calculate the income elasticity of imports.

The over-identifying restriction is : $$\frac{p_{32}}{b_{12}} = \frac{p_{33}}{b_{13}}$$

and the income elasticity of imports is given as:

$$b_{31} = p_{31} - \frac{p_{32}}{b_{12}} b_{11} = p_{31} - \frac{p_{33}}{b_{13}} b_{11}$$

The reduced form of the model, given in equations (27)-(29), suggests that the error term of equation (29) is correlated with the error term of equation (27). We, therefore, estimate these two equations jointly using an iterative seemingly unrelated regression (ISUR) procedure, which is equivalent to maximum likelihood. Given the heterogeneity of the sample of countries, the residuals from the estimation suffer from heteroskedasticity. We therefore apply the method proposed by White (1980), in order to correct this problem. Consequently, the standard errors reported in table (1) are heteroskedasticity consistent. All estimations were carried out using TSP version 4.4.

Three variants of the model are estimated and these are presented in Table 1. The infrastructure equation is the same in all three cases while the imports equation differs depending on whether and how foreign infrastructure is included. The first variant of the model, given in column 1, includes the equally weighted sum of foreign infrastructure investment while the second variant, in column 2, includes the sum of trade weighted foreign infrastructure investments, $SWZG_j$. Finally, the third variant excludes foreign infrastructure investment altogether, treating it as an endogenous variable depending on foreign income, in which case the coefficient of the latter should be interpreted accordingly.

All the coefficients for equation (27), which determines infrastructure investment, have signs predicted by the theory and are statistically significant. In particular, the structural coefficients confirm that domestic infrastructure investment is increasing in domestic real GDP and decreasing in foreign income. Thus, one of the central predictions of the theoretical model is supported by the data. Also, as expected, the real interest rate has a negative effect on public infrastructure investment.

All bar one of the coefficients of the import demand equation (29) also have the expected sign. In all three variants of the model the estimated coefficients of domestic real income are positive and significant. Positive coefficients are also found in the case of foreign public investment in variants 1 and 2 of the model, even though in column 1 this variable marginally fails the test of statistical significance. The implied values for the income elasticity of imports are statistically significant and, even though not precisely estimated, fall in the range of those found in the literature[15]. Remoteness from trading partners has the expected negative sign and is highly significant. Furthermore, coefficients of the real interest rate are negative though highly insignificant. Finally, even though the coefficients of the sum of foreign real GDP's are positive, only the one in column 3 is significant. As explained in section 4, this is not inconsistent with our model, since the equation reported in column 3 omits foreign infrastructure from the right-hand variables. As a result, the coefficient of income in column 3 also captures the dependence of total foreign infrastructure on total foreign income, which is likely to be positive. Indeed, the increased value of this coefficient from approximately 0.40 in columns 1 and 2 to 0.78 in column 3 confirms that this is the case.

[15]In an extensive survey of the literature Deyak, Swayer and Sprinkle (1993) find a range from 0.51 to 2.72 for the income elasticity of imports.

In the preceding section, following our theoretical model, we have assumed that domestic income is exogenous. However, empirically this assumption may not hold, which may render the results in table 1 biased and inconsistent. We therefore also report results from estimation of the model where domestic income is instrumented by the lag of domestic income, employing the method of three stage least squares (3SLS) for estimation. Again all three variants of the model are estimated.

The results from the 3SLS estimation are set out in table 2. The coefficients and t-statistics are very similar to those found when domestic income is assumed exogenous[16]. In particular, the result that infrastructure investment is negatively related to the sum of all trading partners' incomes is found to be robust.

VII Conclusion

In a recent related paper Bougheas, Demetriades and Morgenroth (1997) examine the effect of infrastructure on specialisation and the volume of trade within a Ricardian framework. While explicitly considering the resource cost of infrastructure and modelling its influence on transport costs, the symmetric structure of that model restricts both the theoretical and the empirical analysis to countries with similar endowments. The important question of how countries would share the cost of providing international transport services is, therefore, not addressed. Thus, the current paper takes the argument several steps further. Most importantly, it addresses the question of whether the equilibrium level of infrastructure would be optimal. The answer to this question not only has significant implications for international policy co-ordination but also fills an important gap in the existing literature on

[16] Since estimation using 3SLS makes little difference to the results one might suspect that income is indeed exogenous. This is confirmed by Hausman tests which show that for both equation 27 and 29 estimation using ISUR is consistent.

infrastructure which has not, so far, provided theoretical models to explain why public infrastructure may be supplied at sub-optimal levels. Furthermore, the generalised nature of the model, particularly the relaxation of symmetry, provides better scope for empirical testing of the model.

Our results have important policy implications, particularly for trading blocks such as the European Union. According to our model, such blocks are likely to be better off by addressing the co-ordination problem associated with the provision of trade-promoting public infrastructure. While the European Structural Funds are aimed at economic growth and recovery of regions which are underdeveloped by comparison with the Community average, they are not specifically designed to address co-ordination failures of this type[17]. Yet they are particularly well suited for this purpose since optimal provision of public capital is also likely to raise the rate of return of public capital, thereby increasing economic growth[18]. Given that the current regulations for the Funds are about to expire in 1999, future reforms, which are under way, offer the opportunity to explicitly take into account market failures[19].

The need to centralise public infrastructure provision is, in fact, widely recognised within federal systems. For example, in Germany and the US highway construction and maintenance is the responsibility of the federal authorities. The view that whenever public goods or services have spill-out effects or externalities beyond the jurisdictions that supply them may result in under-provision is, of course, well founded in the literature on fiscal federalism and has its roots in Pigou's externality theorem (Oates, 1991; Quigley, 1997). By re-interpreting our model as representing two trading federal states in a closed economy context, our under-provision result becomes consistent with the predictions of this literature. The novelty of our paper remains, however, that we have shown, both theoretically and

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[17] This is Objective 1 of the Structural Funds. Other objectives are aimed at the creation of employment and re-structuring of labor markets.
[18] Goybet and Bertoldi (1994) argue along similar lines. The theoretical relationship between infrastructure and economic growth is explored in Bougheas and Demetriades (1997).

empirically, that under-provision of public infrastructure could also be the result of international co-ordination failures in an international trade settting. The policy relevance of our result cannot, therefore, be overstressed. While federal states customarily address spill-outs or externalities across their jurisdictions, either through a system of inter-governmental transfers or by centralising decisions regarding public goods, this is clearly very rarely the case for independent nations that trade with each other.

[19] See Begg (1998) for an up to date account of the reform of the European Structural Funds and the related Agenda 2000 proposals.

Table 1 Estimation Results using Iterated Seemingly Unrelated Regression (ISUR)

Equation (27) (dependent variable ZG_i)	(1)	(2)	(3)
Y_i	0.85 (17.13)	0.85 (17.13)	0.85 (17.13)
SY_j	-0.63 (2.05)	-0.63 (2.05)	-0.63 (2.05)
CI_i	-0.058 (1.98)	-0.058 (1.98)	-0.058 (1.98)
R^2	0.89	0.89	0.89
Equation (29) (dependent variable M_i)			
Y_i	0.71 (18.94)	0.65 (17.43)	0.71 (17.94)
SY_j	0.40 (1.37)	0.38 (1.41)	0.78 (3.37)
CI_i	-0.006 (0.26)	-0.0041 (0.18)	-0.01 (0.47)
SZG_j	0.72 (1.95)		
$SWZG_j$		0.55 (3.73)	
R_i	-0.58 (8.18)	-1.03 (6.87)	-0.58 (8.03)
Number of observations	56	56	56
R^2	0.81	0.83	0.81
Income elasticity (b_{31})	1.26 (2.81) 0.62 (1.69)	1.16 (2.59) 0.59 (1.77)	1.75 (2.93) 0.53 (1.44)
Wald test of the overidentifying restriction	1.09 (0.29)	0.86 (0.35)	3.46 (0.06)

Constants are included in all regressions but are not reported here. The t-statistics in parentheses are derived from heteroskedastic consistent standard errors. The Wald tests of the overidentifying restrictions are c^2 tests, with one degree of freedom, for which we report the test statistics with p-values in parentheses.

Table 2 Estimation Results using Three Stage Least Squares (3SLS)

Equation (27) (dependent variable ZG_i)	(4)	(5)	(6)
Y_i	0.85 (17.29)	0.85 (17.05)	0.85 (17.19)
SY_j	-0.64 (2.08)	-0.64 (2.09)	-0.64 (2.08)
CI_i	-0.058 (1.98)	-0.058 (1.98)	-0.058 (1.98)
R^2	0.89	0.89	0.89
Equation (29) (dependent variable M_i)			
Y_i	0.71 (18.04)	0.66 (16.51)	0.69 (17.34)
SY_j	0.44 (1.48)	0.46 (1.68)	0.80 (3.40)
CI_i	-0.006 (0.27)	-0.0051 (0.22)	-0.01 (0.46)
SZG_j	0.68 (1.73)		
$SWZG_j$		0.46 (2.97)	
R_i	-0.52 (7.18)	-0.88 (5.46)	-0.52 (7.17)
Number of observations	56	56	56
R^2	0.81	0.83	0.80
Income elasticity (b_{31})	1.30 (2.82) 0.61 (1.66)	1.27 (2.78) 0.58 (1.71)	1.76 (2.99) 0.53 (1.42)
Wald test of the overidentifying restriction	1.26 (0.25)	1.24 (0.26)	3.5 (0.058)

Income is instrumented with lagged income. Constants are included in all regressions but are not reported here. The t-statistics in parentheses are derived from heteroskedastic consistent standard errors. The Wald tests of the overidentifying restrictions are c^2 tests, with one degree of freedom, for which we report the test statistics with p-values in parentheses.

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Appendix not intended for publication

For simplicity we set $q_{ij} = 1$ for $i = H, F$; $j = h, f$.

1. The slope of the reaction function.

Let $A \equiv \frac{1}{\left(z_H - z_{HG}\right)^2} > 0$

$$B \equiv \frac{1}{\left(z_F - z_{FG}\right)^2} > 0$$

$$C \equiv \frac{g_H^{''} g_H - \left(g_F^{'}\right)^2}{\left(g_F\right)^2} < 0$$

$$D \equiv \frac{g_F^{''} g_F - \left(g_F^{'}\right)^2}{\left(g_F\right)^2} < 0$$

$$E \equiv \frac{g^{''} g - \left(g_F^{'}\right)^2}{\left(g\right)^2} < 0$$

By totally differentiating (10), the home country's reaction function, we get:

$$-Adz_H + Adz_{HG} = Cdz_{HG} + Edz_{HG} + Edz_{FG}$$

The slope is given by:

$$\frac{\partial z_{HG}}{\partial z_{FG}} = \frac{-E}{C + E - A} \quad \text{and} \quad 0 < \left|\frac{E}{C + E - A}\right| < 1$$