

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 16 European countries over the period 1987-95, 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

1. 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 literature¹, 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 Karas, 1994, Holtz-Eakin, 1994), others have found positive effects (e.g. Naderi 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, 2000).

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. For example, if Britain were to improve its road and rail network, this is likely to benefit French producers, as it would make it cheaper to get French goods to small towns throughout Britain. Similarly, infrastructure investments in France are likely to benefit British producers. This could hold for infrastructure investment in any country, as long as it has trade links with the rest of the world. Infrastructure, therefore, has characteristics of an international public good, which suggests that its provision may be subject to an international co-

¹ See Gramlich (1994) for an extensive review of the literature.

ordination problem .

While the link between transport costs and trade is commonplace in the trade literature², 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 (1999) 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 infrastructure 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 costs³. 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.

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 markets⁴. Specifically, we assume that the two social planners

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.

⁴ Fisher and Mirman (1992), Datta (1997) and Mirman and Datta (2000) use the same approach to study dynamic externalities.

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 data from 16 European countries over the period 1987-95. Our empirical results accord well with our theoretical predictions. Importantly, the international strategic nature of public infrastructure investment is strongly 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, provides the equilibrium and examines its efficiency aspects. Section 3 formulates the econometric model, describes the data used for estimation and presents the empirical results. Finally, section 4 summarises and concludes.

2. Theoretical Model and Predictions

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 costs⁵. 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:

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

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

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

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

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

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 maximizing, 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:

$$(4) U_i(c_h, c_f) \equiv \alpha_h \log c_h + \alpha_f \log c_f, \quad i = H, F$$

With the above functional form we can get closed form solutions without imposing any further restrictions on the infrastructure technologies⁶. 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 specifications. Our method of solution is as follows. The first step is to solve each representative agent's maximization problem. Each agent takes prices, p_h and p_f , and his income, $y_i = z_i - z_g$, 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 ($p \equiv p_f / p_h$) 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 maximizes the corresponding indirect utility function by choosing his country's investment in infrastructure and taking the other

⁶ See also the discussion in the following section.

planners'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.

2.1. Voluntary Contributions

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

$$\text{Max } \alpha_{Hh} \log c_{Hh} + \alpha_{Hf} \log c_{Hf} ,$$

$$\text{subject to: } p_h \frac{c_{Hh}}{g_H} + p_f \frac{c_{Hf}}{g} = p_h Y_H$$

The solution is given by:

$$(5) \quad c_{Hh} = \frac{\alpha_{Hh}}{\alpha_{Hh} + \alpha_{Hf}} g_H Y_H \quad \text{and} \quad c_{Hf} = \frac{\alpha_{Hf}}{\alpha_{Hh} + \alpha_{Hf}} \frac{g}{p} Y_H$$

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. The equilibrium allocations must also satisfy the corresponding solution for country F and the following feasibility constraints:

$$(6) \quad z_H - z_{HG} \geq \frac{c_{Hh}}{g_H} + \frac{c_{Fh}}{g}$$

$$(7) \quad z_F - z_{FG} \geq \frac{c_{Ff}}{g_F} + \frac{c_{Hf}}{g}$$

The left-hand side of each expression is equal to the production of the domestic good which is also equal to income. The righthand side shows the

allocation of production between domestic consumption and exports. The equilibrium relative price (terms of trade) is given by:

$$(8) \quad p = \frac{c_{Fh}/g}{c_{Hf}/g} = \frac{q_{Hf}(q_{Ff} + q_{Fh})}{q_{Fh}(q_{Hh} + q_{Hf})} \frac{z_F - z_{FG}}{z_H - z_{HG}}$$

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), (8), 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} :

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

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

$$(9) \quad q_{Hh} \frac{1}{z_H - z_{HG}} = q_{Hh} \frac{g'_H(z_{HG})}{g_H(z_{HG})} + q_{Hf} \frac{g'(z_{HG} + z_{FG})}{g(z_{HG} + z_{FG})}$$

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.

Lemma 1:

The reaction function has a negative slope with an absolute value less than one.

Proof:

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

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

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

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

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

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

By totally differentiating (9), the home country's reaction function, we get:

$$-A dz_H + A dz_{HG} = C dz_{HG} + E dz_{HG} + E dz_{FG}$$

The slope is given by:

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

The social planner of F faces a similar optimisation problem which yields a corresponding reaction function. The following conditions hold at the unique Cournot-Nash equilibrium, found by the intersection of the two reaction functions.

$$(10) \quad \frac{dz_g}{dz_i} > 0 \text{ and } \frac{dz_g}{dz_j} < 0; \quad i, g = H, F \quad i \neq j.$$

Investment in infrastructure in both countries is increasing in their own endowment but decreasing in the other country's endowment. It is useful to compare this aspect of the non-co-operative solution to the co-operative outcome.

2.2. Global Social Efficiency

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 the optimization problem is the following:

$$\begin{aligned} \text{Max } & \alpha_{Hh} \log c_{Hh} + \alpha_{Hf} \log c_{Hf} + \alpha_{Ff} \log c_{Ff} + \alpha_{Fh} \log c_{Fh} \\ \text{subject to } & (6) \text{ and } (7). \end{aligned}$$

Lemma 2:

The solution of the co-operative case yields the following two conditions:

$$(11) \quad \frac{\alpha_{Hh} + \alpha_{Fh}}{z_H - z_{HG}} = \alpha_{Hh} \frac{g'_H(z_{HG})}{g_H(z_{HG})} + (\alpha_{Hf} + \alpha_{Fh}) \frac{g(z_{HG} + z_{FG})}{g(z_{HG} + z_{FG})}$$

$$(12) \quad \frac{\alpha_{Ff} + \alpha_{Hf}}{z_F - z_{FG}} = \alpha_{Ff} \frac{g'_F(z_{FG})}{g_F(z_{FG})} + (\alpha_{Hf} + \alpha_{Fh}) \frac{g(z_{HG} + z_{FG})}{g(z_{HG} + z_{FG})}$$

Proof: See Appendix 1. \square

Equations (11) and (12) jointly determine the co-operative solution for investment in infrastructure by the two countries. Next, we compare these solutions with the reaction function, (9). Without loss of generality, we impose the following restriction:

Assumption 1:

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

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

Since the solutions for the two countries are symmetric, we concentrate on (11) and (9), 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 righthand 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 righthand 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 global social planner also considers the benefits for country F . This effect leads to under-investment.

Let $*$ denote the non-co-operative solutions. After subtracting (9) from (11), we arrive at the following result:

Proposition 1:

$$\text{If } \alpha_{FH} \left\{ \frac{g(z_{HG}^* + z_{FG}^*)}{g(z_{HG}^* + z_{FG}^*)} - \frac{1}{z_H - z_{HG}^*} \right\} > 0$$

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 terms of trade will also induce a substitution effect which would weaken the strength of the second term⁸.

3. Econometric Model and Results

In order to test the predictions of our theory we construct a simple econometric model of infrastructure investment which is specified in per capita terms. This specification is consistent with the theoretical results since these are derived in the context of a representative agent model and also helps

⁷ By symmetric preferences we mean that $\alpha_{HH} = \alpha_{FF}$ and $\alpha_{HF} = \alpha_{FH}$.

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.

reduce the effect of the size heterogeneity between the countries in our data set. 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 policymakers. In order to move from a two-country model to the realities of a multi-country setting, we adopt the convention that the 'foreign country' represents all the trading partners of the domestic economy.

3.1 Model Specification

Our model of infrastructure investment is specified in log-linear form and relates the logarithm of per capita infrastructure investment of a country i , denoted i_t , to per capita income in that country, y_i , per capita income in other countries, fy_j , and a number of variables that capture the characteristics of the country in question, x_i . Since the model will be estimated using panel data all variables are further subscripted to indicate a specific time period. The estimation equation therefore takes the following form :

$$(13) \quad i_{it} = a_{it} + b_1 y_{it} + b_2 fy_{jt} + bx_{it} + u_{it}$$

where i indexes countries and $i=1.....n$, and indexes t time periods where $t=1.....T$.

On first inspection this specification appears to be similar to that adopted by Case et al (1993). However, following the results of our theoretical model the spillover in our empirical model arises through foreign income rather than foreign expenditure. Furthermore, our model focuses on investment rather than total expenditure⁹. This specification also simplifies estimation since the foreign income variable can be treated similarly to any other explanatory

⁹ The proportion of total expenditure that is allocated to investment varies significantly between countries. For those countries for which data is available for investment and maintenance the proportion that goes to investment varies between 38% and 87% of total expenditure.

variable, thus allowing us to estimate the model using ordinary least squares (OLS), while the inclusion of foreign infrastructure investment would require maximum likelihood estimation (ML)¹⁰.

3.2. Specification of foreign income

Since our aim is to test the effect of foreign income on domestic infrastructure investment, the specification of the foreign income variable is particularly important. Since countries can observe more than one neighbour at a time the income of every foreign country should be estimated separately. However, this would imply a significant loss of degrees of freedom that renders this approach impossible in cross-section estimation. Furthermore, the estimation of $n-1$ foreign income coefficients is likely to introduce multicollinearity. In order to overcome these problems it is customary to impose some structure on the specification of the foreign variable that results in the estimation of only one parameter. This is achieved through the use of a spatial weights or connectivity matrix, w , which has to be specified by the researcher. This weights matrix consists of individual elements w_{ij} such that the foreign income variable is specified as a weighted sum :

$$(14) \quad fy_t = \sum_{j=1}^n w_{ij} Y_{jt}$$

or in vector form for each cross-section, with $w_{ii} = 0$

$$FY_t = W Y_t$$

This specification allows us to relate the infrastructure investment at one point in space to the income in other points in space, and we refer to the foreign income as the spatial lag of income¹¹. An important issue is the choice of the weights, w_{ij} . One of the most widely used specification of these spatial weights is based on the concept of connectivity which is measured as a binary variable which is equal to one if countries i and j have a common border and

¹⁰ See Anselin 1988, or Haining, 1990.

¹¹ The term spatial lag refers to the fact that the observations are neighbours in space rather than in time as would be the case in time series analysis where the lag would refer to the value of a variable in the previous time period.

zero if they do not have a common border¹². This implies that such a specification assumes that only neighbouring countries have an effect on the investment decision of the home country. Another widely used specification utilises the distance or inverse distance between two countries, which implies a distance decay of the effect of foreign countries. Of course the theoretical model also suggests a specification of the spatial weights, namely trade weights implying that foreign countries with which the home country trades more have a larger impact.

As is customary we scale the weights so that they sum to one such that:

$$(15) \quad w_{ij} = \frac{w_{ij}}{\sum_j w_{ij}}$$

This renders the spatial weights matrix non-symmetric but facilitates the interpretation of the results since this imposes the restriction that the sum of the neighbours of each country are treated equally.

3.3. Data

Our data set consists of annual observations for the period 1987 to 1995 covering 16 European countries, namely Austria, Belgium/Luxembourg, Denmark, Finland, France, Germany, Greece, Ireland/Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. The choice of countries was determined by the availability of road investment data. In order to account for the specific characteristics of each country we include a set of additional variables, x_{it} , which are further outlined in this section. In order to take account of scale effects we include size of the population, p_{it} . Since countries with a high population density can achieve a given road service level with fewer roads than countries that have a scattered low-density population we include population density, pd_{it} in our specification. Another important variable is the existing stock of roads since countries that have already completed a road network will need less additional investment than

¹² Moran (1948) and Geary (1954) first proposed binary contiguity between spatial units in their pioneering papers on measures of spatial dependence.

countries that are still building up a road network. We therefore include the density of the existing road stock, $rden_{it}$. However, as this was found to be highly collinear with population density, this variable is included in a specification that excludes population density¹³. Furthermore, financing issues may also be important determinants of investment. Thus, countries with a high level of debt are likely to reduce their investment in order to improve their fiscal position. To capture this effect we include the government debt expressed as a percentage of GDP, de_{it} . Furthermore, interest rates that impact on the willingness to borrow for investment are also likely to play an important role, and we include the long-run interest rate, ir_{it} in our specification. As our sample consists of European countries, some of which have been receiving large transfers from the EU Commission as part of the Structural Funds in order to improve their infrastructure. To take this effect into account we include a dummy variable, coh_{it} which is equal to one, from 1988 onwards, for those in the countries that received the bulk of EU aid. Thus, we specify two infrastructure investment equations that are defined as follows:

$$(16) \quad i_{it} = a_z + b_1 y_{it} + b_2 fy_{it} + b_3 p_{it} + b_4 pd_{it} + b_5 de_{it} + b_6 ir_{it} + b_7 coh_{it} + u_{it}$$

$$(17) \quad i_{it} = a_z + b_1 y_{it} + b_2 fy_{it} + b_3 p_{it} + b_4 rden_{it} + b_5 de_{it} + b_6 ir_{it} + b_7 coh_{it} + u_{it}$$

These are estimated using three different specifications of the foreign income variable, namely one using binary contiguity weights, one using trade weights and one using inverse distance weights. Overall we attach particular importance on b_2 in equations 13 and 14, which we expect to be negative, reflecting the strategic nature of domestic infrastructure investment decisions.

Specifically the data were drawn from the following sources. Gross Investment in Roads in constant 1995 ECU was obtained from the report of the European Conference of Ministers of Transport (1999) entitled "Investment in Transport Infrastructure 1985-1995: Country Studies". This was converted to US Dollars

¹³ The use of the road density variable also results in a reduction of the number of observations since road length could not be obtained for Portugal.

using the ECU/\$ exchange rate from the OECD Economic Outlook. Population, the long-run interest rate and GDP in constant 1995 US Dollars, PPP adjusted, were also obtained from the OECD Economic Outlook. In the case of Greece the long-run interest rate could not be obtained from the OECD, IMF or Eurostat, and hence the short-run interest rate was used instead.

The spatial weights used are the binary contiguity weights¹⁴, distance weights and trade weights. The road length was obtained from the International Road Federation World Road Statistics Year Books. The contiguous countries for each country are outlined in the appendix. The distance weights refer to great circle distance between the centre of each country¹⁵, and this was calculated using the SpaceStat programme (see Anselin, 1995) in conjunction with the ArcView GIS package. The trade weights are derived using total trade, that is imports plus exports between country pairs, where the trade data was obtained from UN International Trade Statistics. In order to obtain a reasonable sample size for estimation all the observations are pooled, yielding a sample of 144 observations.

3.4. Estimation and Results

As was outlined above the fact that we use the spatial lag of foreign income rather than foreign road investment allows us to use OLS for estimation. However, our model may be subject to spatial dependence in the error term which could result in inconsistent estimates of the standard errors of the parameters. The standard approach in the regional science literature is to either apply Feasible Generalised Least Squares (FGLS) or Maximum Likelihood (ML) that take account of the spatial dependence of the error term¹⁶. To implement these methods it is necessary to impose strong parametric restrictions on the relationship between the residuals. This is achieved through the use of a spatial weights matrix similar to those used to

¹⁴ The contiguities are shown in table 5 in the appendix.

¹⁵ Alternatively the distances between capital cities could also be used. However, the use of these distances does not alter the results significantly.

¹⁶ Anselin, 1988 contains a detailed review of this literature.

define the foreign income variable described above such that the error term for each cross section is written as:

$$(18) \quad u_t = \lambda W u_t + e_t$$

where e_t represents an independent and identically distributed error term, λ , represents the spatial autocorrelation coefficient and W , represents a spatial weights matrix. However, these methods are concerned with simple cross-section models and are sensitive to other misspecifications such as heteroskedasticity.

An alternative method to deal with spatial autocorrelation was developed recently by Driscoll and Kraay (1998). Their method not only deals with spatial autocorrelation, but it also allows for the calculation of standard errors that are robust to heteroskedasticity and serial correlation. It has the further advantage that it requires no prior knowledge of the form of spatial dependence or serial correlation, and therefore requires no explicit parameterisation of the form of the dependence. This method applies the well known Newey-West covariance matrix (see Newey and West, 1987) to the sequence of cross-sectional averages of the vector of functions of the data and parameters that is used in forming the orthogonality conditions for generalised methods of moments estimation. While this method applies to instrumental variables (IV) estimation, OLS estimation is carried out by using the regressors as instruments. Since the exact form of spatial autocorrelation is not of particular interest this latter method which is also straightforward to implement is used here. However, this procedure requires the number of estimated parameters to be smaller than the number of time periods. Our estimation equation contains 8 parameters plus 9 parameters for time specific effect and we have just 9 time periods it is necessary to reduce the number of parameters. However, it is straightforward to reduce the number of parameters by subtracting the mean of the series appropriately¹⁷.

¹⁷ This prevents us from estimating the parameters for the constant and the time specific effect but leaves all other coefficients unaffected. Estimation with country specific effects proved difficult as the country dummies were highly multicollinear with the other right hand

In order to obtain benchmark results against which the results of our full model can be judged, we estimate the infrastructure investment equations excluding the sum of the foreign incomes using ordinary least squares estimation (OLS)¹⁸. The results from this estimation of the two base specifications are shown in Table 1 and 2, confirm that the income of the home country has a significant positive effect on infrastructure. Countries with a larger population invest more countries with a higher population density invest less. A high debt to GDP ratio decreases investment as does a higher long run interest rate. The Cohesion Countries, Greece, Ireland, Portugal and Spain which receive high levels of Structural Funds assistance invest more in infrastructure.

Turning to the estimation of the fully specified equations the results are presented in columns 2 to 4 and 5 to 8 of the same tables. We observe that all the coefficients have the predicted signs and are statistically significant. Furthermore, the inclusion of the foreign infrastructure variables adds significantly to the explanatory power of the model, particularly in the case of the trade weighted foreign income. Notably the results confirm that domestic infrastructure investment is increasing in domestic real GDP and decreasing in foreign income, irrespective of the definition of the latter. Thus, one of the central predictions of the theoretical model appears to be strongly supported by the data.

The standard errors obtained controlling for heteroskedasticity and spatial autocorrelation, are considerably smaller compared to alternatives (OLS, White and Newey –W est), which supports the finding of Driscoll and Kraay (1998), that this technique dominates the alternatives even in finite samples.

side variables. Thus, while they improved the fit of the regressions, only one parameter was found to be statistically different from zero.

¹⁸ All estimations were carried out using TSP version 4.4, and the standard errors are derived using the TSP code available from John Driscoll's web site at <http://econ.psrc.brown.edu/~td/>.

Table 1. Estimation Results OLS including Population Density

	1	2	3	4
GDP	1.38 (0.18)	1.59 (0.18)	1.48 (0.18)	1.49 (0.14)
Foreign GDP				
FirstOrderContiguityWeights		-0.59 (0.13)		
TradeWeights			-2.07 (0.56)	
DistanceWeights				-3.49 (0.83)
POP	0.19 (0.02)	0.19 (0.02)	0.19 (0.02)	0.19 (0.01)
POPDENS	-0.17 (0.01)	-0.18 (0.01)	-0.16 (0.01)	-0.19 (0.01)
LRI	-0.69 (0.09)	-0.69 (0.10)	-0.65 (0.11)	-0.69 (0.09)
DEBT	-0.35 (0.03)	-0.32 (0.03)	-0.35 (0.03)	-0.29 (0.03)
COH (88)	0.31 (0.07)	0.27 (0.06)	0.26 (0.06)	0.21 (0.07)
N	144	144	144	144
\bar{R}^2	0.76	0.76	0.76	0.77

The standard errors are those obtained using the Driscoll and Kraay (1998) method, controlling for heteroskedasticity and spatial autocorrelation of the residual.

Table 2. Estimation Results OLS including Road Density

	5	6	7	8
GDP	1.38 (0.18)	1.62 (0.17)	1.45 (0.17)	1.36 (0.14)
Foreign GDP				
FirstOrderContiguityWeights		-1.17 (0.24)		
TradeWeights			-3.05 (0.72)	
DistanceWeights				-4.08 (1.20)
POP	0.15 (0.02)	0.13 (0.02)	0.14 (0.02)	0.13 (0.02)
ROADENS	-0.23 (0.02)	-0.22 (0.02)	-0.20 (0.02)	-0.21 (0.01)
LRI	-0.79 (0.09)	-0.73 (0.11)	-0.70 (0.12)	-0.72 (0.10)
DEBT	-0.30 (0.03)	-0.29 (0.03)	-0.32 (0.03)	-0.28 (0.03)
COH (88)	0.36 (0.09)	0.25 (0.06)	0.29 (0.07)	0.22 (0.09)
N	135	135	135	135
\bar{R}^2	0.72	0.73	0.73	0.73

The standard errors are those obtained using the Driscoll and Kraay (1998) method, controlling for heteroskedasticity and spatial autocorrelation of the residual.

The OLS estimates presented in Table 1 and 2 implicitly assume that domestic income is exogenous. To examine the robustness of our results to this assumption, we also estimate the infrastructure equations using instrumental variable (IV) estimation, where domestic income is instrumented by the lag of domestic income. The results from the IV estimation are set out in Table 3 and 4. The coefficients are very similar to those found using ordinary least squares and one can therefore conclude that endogeneity is not a problem. Thus, the result that infrastructure investment is negatively related to the sum of all trading partners' incomes is found to be robust. The fact that the parameter on the foreign income variables is negative in each case despite the differences in the weights matrices highlights the robustness of our results.

Table 3. Estimation Results IV including Population Density

	9	10	11	12
GDP	1.40 (0.19)	1.66 (0.20)	1.53 (0.21)	1.56 (0.15)
Foreign GDP				
First Order Contiguity Weights		-0.62 (0.12)		
Trade Weights			-2.11 (0.58)	
Distance Weights				-3.54 (0.80)
POP	0.19 (0.02)	0.19 (0.02)	0.19 (0.02)	0.19 (0.02)
POP DENS	-0.17 (0.01)	-0.18 (0.01)	-0.16 (0.01)	-0.19 (0.01)
LRI	-0.69 (0.10)	-0.67 (0.10)	-0.63 (0.11)	-0.67 (0.09)
DEBT	-0.35 (0.03)	-0.31 (0.03)	-0.35 (0.03)	-0.29 (0.04)
COH (88)	0.31 (0.07)	0.28 (0.07)	0.28 (0.06)	0.23 (0.07)
N	144	144	144	144
\bar{R}^2	0.76	0.76	0.76	0.77

The standard errors are those obtained using the Driscoll and Kraay (1998) method, controlling for heteroskedasticity and spatial autocorrelation of the residual.

Table 4. Estimation Results IV including Road Density

	1	2	3	4
GDP	1.41 (0.20)	1.71 (0.19)	1.51 (0.19)	1.42 (0.15)
Foreign GDP				
FirstOrderContiguityWeights		-1.21 (0.23)		
TradeWeights			-3.07 (0.74)	
DistanceWeights				-4.07 (1.17)
POP	0.15 (0.02)	0.13 (0.02)	0.14 (0.02)	0.13 (0.02)
POPDENS	-0.23 (0.02)	-0.22 (0.02)	-0.20 (0.02)	-0.21 (0.02)
LRI	-0.78 (0.10)	-0.71 (0.12)	-0.69 (0.12)	-0.71 (0.10)
DEBT	-0.30 (0.03)	-0.28 (0.03)	-0.32 (0.03)	-0.27 (0.03)
COH (88)	0.34 (0.09)	0.27 (0.07)	0.30 (0.07)	0.24 (0.09)
N	135	135	135	135
\bar{R}^2	0.72	0.73	0.73	0.73

The standard errors are those obtained using the Driscoll and Kraay (1998) method, controlling for heteroskedasticity and spatial autocorrelation of the residual.

Given that the spatial lag of foreign income was measured by a weighted sum some further comments about the interpretation of the results are in order. Firstly, it should be noted that a one percent increase in all 15 foreign countries' per capita GDP will result in a one percent increase in the foreign variables, for both the trade and the distance weighted foreign incomes. For the contiguity weighted sum this depends on number of contiguous countries. For example, Austria has just three neighbours so a one percent increase in one of these countries' income would result in an increase in the contiguity weighted foreign income of one third of a percent. For the other two spatially lagged foreign income variables the impact of an increase of the per capita GDP of one country on the investment decision in another, depends on the weight it is given in the spatial weights matrix. This in turn depends on either the distance between the two countries or the trade share.

To see how the spatial weights matrix determines the effect of the income in one country on the investment decision in another it is instructive to take an

example. Take the investment decision of Belgium and the income of France and Finland. Since Finland is not a neighbour of Belgium it has a zero weight in the contiguity matrix, while France is one of the four neighbours of Belgium and thus has a weight of one quarter. However, since the per capita GDP of France is slightly higher than the average for the four neighbouring countries of Belgium, a one percent increase in French per capita GDP will result in an increase of just over one quarter of a percent in the contiguity weighted foreign GDP of Belgium. Turning to the trade and distance weighted foreign GDP's the weights for France are 0.2242 and 0.155341 respectively, while those for Finland are 0.0082 and 0.024261 respectively. These imply that a one percent increase in the per capita GDP of France results in a 0.23% increase in the trade weighted foreign income and 0.16% increase in the inverse distance weighted sum of foreign income of Belgium. A similar increase in the per capita GDP of Finland gives rise to an increase of 0.01% and 0.02% of the spatially weighted foreign income measures respectively. This example highlights that the three spatial weights give substantially different importance to individual countries.

These differences in the weighting schemes also explain the differences in the size of the parameter. This is easily demonstrated by a simple example that results in a one percent increase in the weighted foreign income variable. Again, taking the case of Belgium for 1995, a one percent increase in the GDP of all other countries would result in a one percent increase of the trade and distance weighted sums of foreign income. However, a one percent increase in the per capita GDP of just four countries, namely France, Germany, the Netherlands and the UK would yield a one percent increase of sum of the contiguity weighted foreign income. In the former case this would amount to a total increase of \$2936.15 while the latter would be achieved through an increase of just \$818.99. Thus, apart from attributing contrasting importance to individual countries the particular weighting scheme also imply differences regarding the absolute size of a change in foreign income needed to achieve a certain change in the weighted sums. If the income of Belgium's four neighbouring countries were to increase by \$2936.15 which is equivalent to a one percent increase in the income of all countries, the impact of such a

change would be 3.6 times larger than the impact of a one percent increase of the income of these four countries alone. Given the parameter estimates the impact from this would be similar to the impact of a one percent increase in all foreign countries using the trade and distance weighted foreign income.

Overall our empirical results endorse our theoretical priors that infrastructure investment in any economy has an important international dimension. Specifically, we find evidence which indicates that infrastructure investment is a strategic decision that can not be examined in isolation of the investment decisions of a country's trading partners. Our findings also suggest that this strategic behaviour arises from the spillovers across national boundaries created by infrastructure investments, which are an important determinant of international transport costs.

4. Conclusion

In a recent related paper Bougheas, Demetriades and Morgenroth (1999) 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. This paper addresses the important question of how countries would share the cost of providing international transport services. 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 coordination but also fills an important gap in the existing literature on 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.

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 type¹⁹. 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 growth²⁰. Given that the current regulations for the Funds will expire in 2006, future reforms offer the opportunity to explicitly take into account co-ordination failures of this type.

The need to centralise public infrastructure provision is, in fact, widely recognised within federal systems. For example, highway construction and maintenance in Germany is the responsibility of the federal authorities. Similarly, in the US, while this is carried out by the state authorities that are legally the owners of highways, it is mostly funded by the federal government. 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). If we re-interpret our model as representing two trading federal states in a closed economy context, our underprovision result would become consistent with the predictions of this literature. The novelty of our paper remains, however, that we have shown, both theoretically and empirically, that underprovision of public infrastructure could also be the result of international co-ordination failures in an international trade framework. The policy relevance of our result cannot, therefore, be over-emphasised. 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

¹⁹ This is Objective 1 of the Structural Funds. Other objectives are aimed at the creation of employment and re-structuring of labour markets.

²⁰ Goybet and Bertolli (1994) argue along similar lines. The theoretical relationship between infrastructure and economic growth is explored in Bougheas, Demetriades and Mamuneas (2000).

public goods, this is clearly very rarely the case for independent nations that trade with each other.

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Appendix 1: Derivation of the co-operative solution

Let l_1 and l_2 denote the Lagrangean multipliers which correspond to the constraints (6) and (7), respectively. Then the first order conditions of this optimization problem are:

$$(A1) \quad \frac{q_{Hh}}{c_{Hh}} = \frac{l_1}{g_H}$$

$$(A2) \quad \frac{q_{Hf}}{c_{Hf}} = \frac{l_2}{g}$$

$$(A3) \quad \frac{q_{Ff}}{c_{Ff}} = \frac{l_2}{g_F}$$

$$(A4) \quad \frac{q_{Fh}}{c_{Fh}} = \frac{l_1}{g}$$

$$(A5) \quad -l_1 + l_1 c_{Hh} \frac{g'_H}{g_H^2} + l_1 c_{Fh} \frac{g'}{g^2} + l_2 c_{Hf} \frac{g'}{g^2} = 0$$

$$(A6) \quad -l_2 + l_2 c_{Ff} \frac{g'_F}{g_F^2} + l_2 c_{Hf} \frac{g'}{g^2} + l_1 c_{Fh} \frac{g'}{g^2} = 0$$

Using (6), (A1) and (A4), we get:

$$(A7) \quad c_{Hh} = \frac{q_{Hh}}{q_{Hh} + q_{Fh}} g_H (z_H - z_{HG}) \text{ and } c_{Fh} = \frac{q_{Fh}}{q_{Hh} + q_{Fh}} g (z_H - z_{HG})$$

Using (7), (A2), and (A3), we get:

$$(A8) \quad c_{Ff} = \frac{q_{Ff}}{q_{Ff} + q_{Hf}} g_F (z_F - z_{FG}) \text{ and } c_{Hf} = \frac{q_{Hf}}{q_{Ff} + q_{Hf}} g (z_F - z_{FG})$$

From (A2) and (A4), we get:

$$(A9) \quad \frac{l_2}{l_1} = \frac{q_{Hf}}{q_{Fh}} \frac{c_{Fh}}{c_{Hf}}$$

Substituting (A7) and (A9) in A(5) yields equation (11). Equation (12) is obtained from A(8), A(9) and A(6).

Table 5. Contiguities used for the contiguity weights

Home Country	Contiguous Countries
Austria	Germany, Italy, Switzerland
Belgium /Luxembourg	France, Germany, Netherlands United Kingdom
Denmark	Germany, Norway and Sweden
Finland	Norway and Sweden
France	Belgium /Luxembourg, Germany, Italy, Spain, Switzerland, United Kingdom
Germany	Austria, Belgium /Luxembourg, Denmark, France, Netherlands, Switzerland
Greece	Italy
Ireland	United Kingdom
Italy	Austria, France, Greece, Switzerland
Netherlands	Belgium /Luxembourg, Germany
Norway	Denmark, Finland, Sweden
Portugal	Spain
Spain	France, Portugal
Sweden	Denmark, Finland, Norway
Switzerland	Austria, France, Germany, Italy
United Kingdom	Belgium /Luxembourg, France, Ireland