Investing In Our Transport Future: A Strategic Framework for Investment in Land Transport

Background Paper Six

Transport Infrastructure Investment and Economic Growth: A Review of the Evidence

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Contents

Table of Figures

SECTION 1: INTRODUCTION

The objective of this paper is to review the theoretical and empirical evidence on the relationship between transport and economic growth. The paper takes the form of a literature review of the nature and magnitude of the effects of transport expenditure on economic growth. It summarises what is known about the linkages between transport and economic growth based on a review of academic studies and other research. The paper seeks to explore the evidence that investment in transport infrastructure and economic performance are positively linked, to better understand arguments for the allocation of resources to the transport sector.

This paper does not attempt to explain in detail the different econometric approaches used to analyse and quantify the link between transport and economic growth.

The paper is organised as follows:

- Section two describes the theoretical role of transport in the economy, and outlines the mechanisms through which transport impacts economic activity;
- Section three gives a brief overview of the different approaches that have been used to measure the economic impact of transport, and deals with some definitional issues;
- Section four reviews the most important academic papers and research reports which have considered the topic over the last 30 years;
- Section five presents a summary and conclusions.

Section 2: The Role of Transport in the Economy

2.0 Introduction

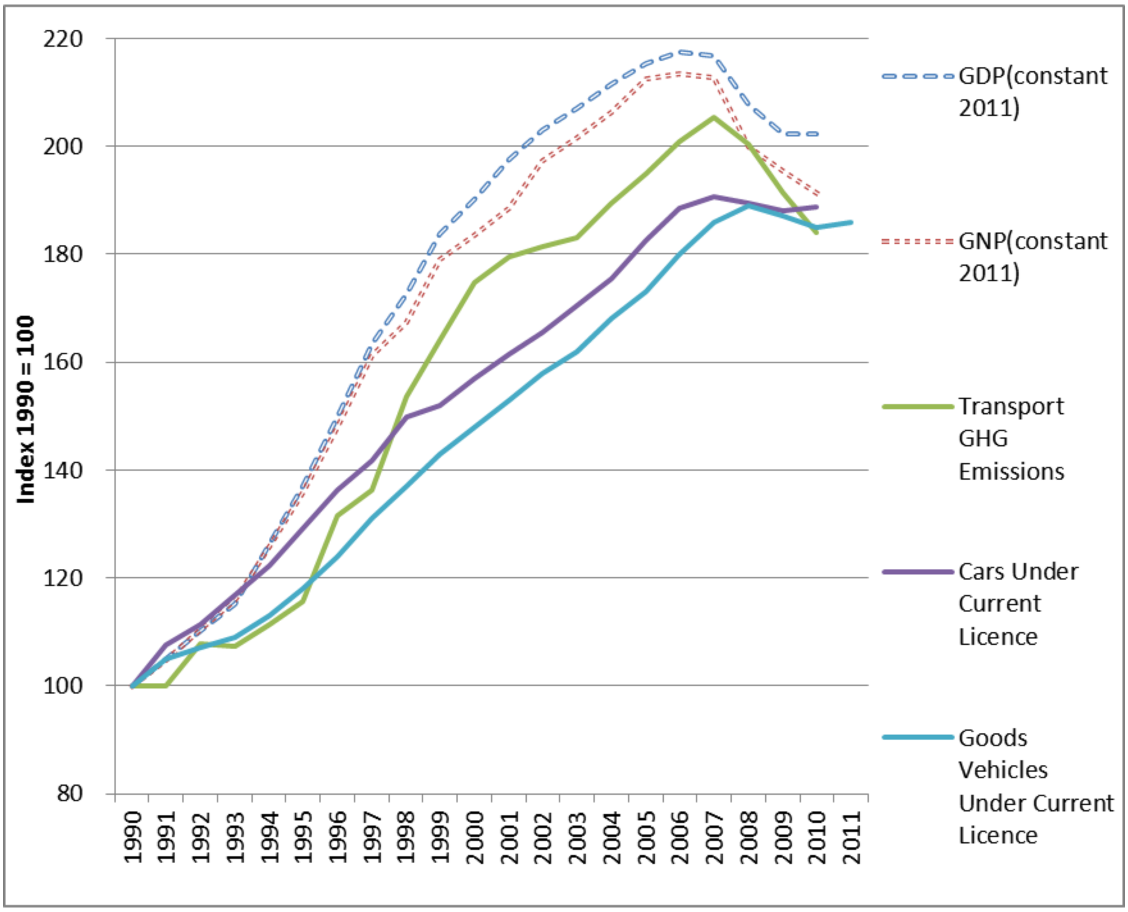
Public investment in infrastructure is viewed as a policy instrument for economic development in almost all countries. Transport in particular has long been recognised as being an important determinant of the location of economic activity. In the standard theory of population and industrial location, transport is defined as a central influence on the location and efficiency of economic activities (Weber, 1928). The long-standing view is that the provision of transport infrastructure affects economic growth either through its direct contribution to the production process or through improving technological innovation, by positively affecting accessibility and integration of transport services (Aschauer, 1989; Hulten and Schwab, 1991).

Improving transport links between geographically separated markets helps to remove trade barriers or productivity bottlenecks (Vickerman, 1987, 1995). Well-provided transport infrastructure has been found to be of importance to the economic development of firms and regions by many authors (Banister and Berechman, 2000).

Many studies that have looked at this issue in the US attribute the step change in productivity that occurred between the end of the Second World War and the end of the 1970s at least in part to the construction of the first interstate highways (Tatom 1991, Gramlich 1994, Hulten and Schwab, 1991, Finn 1993). Other examples of this type of transport-driven step change are apparent in the effect of international shipping routes in opening up early phases of world trade, and the role of the first railways in the creation of industrial cities throughout the world in the 19th century (Crafts and Leunig, 2005). Such inter-urban and international connections have permitted radical new production processes that have allowed regions and countries to engage in trade with each other, enabling them to reap the benefits of increased specialisation in the production of goods and services.

Policymakers have recognised that transport plays an important role in the economy, and developed economies spend substantial sums on investing, maintaining and managing their transport networks. Economic growth in Ireland over the last 20 years has been coupled with increased transport demand. Figure 1 below shows a close correlation between economic output and transport demand over time. It also illustrates that as income rises, private individuals and business increase their use of transport in a similar manner. Growth in transport greenhouse gas emissions in particular has shown a very similar pattern to growth in GNP, and both commercial and private vehicles registration growth are positively correlated with growth in GDP and GNP.

Figure 1: Growth in Transport Greenhouse Gas Emissions, Vehicle Registrations, GNP and GDP, Ireland, 1990-2011



2.1 Rationale for State Involvement

If transport is beneficial to business, why do governments need to get involved in its provision? The rationale for government intervention in the transport market stems from two characteristics of transport, economies of scale and externalities.

The fixed components of transport (roads, railways, bus stations etc.) are costly to build, usually have a long life, and have no or few alternative uses. When transport infrastructure such as this is constructed, the marginal cost of using it decreases until the maximum capacity is reached, which is where the benefit of economies of scale arises. This means that there is a minimum practical level at which provision of infrastructure is economical, which makes the cost of entry to these markets very high. For this reason it has historically been difficult for private companies to construct roads, rail stations and other transport infrastructure.

This is particularly the case for elements of transport services that historically displayed non-excludability[1], such as roads. Traditionally roads were considered non-excludable, but this is increasingly not the case as advances in road pricing technology often now make the consumption of road space excludable.

Scale economies also mean that, where the market does deliver such goods, the tendency is towards consolidation in the market, where a single producer is the most efficient way to deliver the service. In these cases governments intervene to either provide these services or to regulate their provision, to avoid transport services being provided on a monopolistic basis to the detriment of the consumer.

The second characteristic giving rise to government intervention is externalities, which is linked more to the operation and variable costs of transport than to the fixed assets and fixed costs. Once the fixed infrastructure is in place, the operation of transport services creates externalities which generate additional unintended social costs, and benefits, in an economy. The most prominent negative externalities created through the consumption of transport services are congestion and pollution.

These are costs borne by society which governments seek to reduce to increase social utility and economic efficiency. Thus governments intervene in the market for transport services through taxes and subsidies, e.g. in the provision of public transport, with the objective of ameliorating negative externalities (Thomson, 1974).

[1] Non-excludability is a defining feature of public goods, and means consumption of the good cannot be confined to those that have paid for it.

2.1 The Role of Transport in the Economy

Infrastructure in its many forms (telecommunications, water and sewerage networks and transport networks, etc.) has long been considered an important contributor to economic growth. A good transport network is important in sustaining economic success in modern economies as it:

- Links people to jobs;
- Delivers products to markets;
- Underpins supply chains and logistics networks; and
- Facilitates domestic and international trade.

The main role of transport infrastructure, for any nation, is to facilitate connections between spatially divided industries and populations. In the manufacturing and services sectors, the investment in roads helps make transport costs per mile lower in money and time terms. A faster or better quality road means businesses can deliver the same amount of goods both domestically and internationally at a reduced cost.

A road upgrade can reduce vehicle operating costs and increase the speed at which goods can move between seller and buyer. This facilitates economic development because it allows for increased manufacturing and services specialization, and the productivity benefits that come as a result.

Throughout history, step changes in transport provision and advances in transport technology have been associated with periods of accelerated economic growth. Historically, the construction of canals, ports and shipping lines, railways, urban mass transit rail systems, and airports have on each occasion facilitated increased trade between centres of population and economic activity, whether nationally or internationally.

These developments have increased the potential for trade, thus delivering more funds, in the form of tax revenues and profits, which in turn contribute to economic development. Improvements in transport infrastructure have led to reduced journey times, greater reliability and safer routes, and increases in the connections between areas that are geographically separated. These innovations increased international trade and globalisation; they gave people and businesses unprecedented freedom to travel around their own countries and the world developing trade relationships and increasing markets with the aim of creating profits.

Historically infrastructure developments have been associated with reduced cost of business and increased access to markets, which in turn has increased productivity and economic growth. For example, ever-increasing rail, road, air and maritime networks have developed around the world's biggest cities and facilitated their success, by providing large workforces to dense and hugely productive economics. The importance of investment to economic growth has long been recognised. Martin Feldstein wrote… *"the evidence is overwhelming, countries with high rates of saving and investment realise productivity, output growth and quality of life increases more rapidly than those with lower rates"* (Feldstein 1988).

The influential Eddington Study, published by the UK government in 2006, conducted an in-depth analysis of the mechanisms through which transport has impacted economic growth, examining the evidence through time and across countries. The study identified seven key micro driver mechanisms through which transport impacted the UK economy (Table 1).

The Eddington Study also concluded that some of these micro drivers are becoming more important as a result of economic trends:

- the importance of reliability grows with the adoption of just-in-time management techniques;
- the importance of urban areas as centres of highly-productive service industry growth means an increasing role for transport in supporting agglomeration economies; and
- transport's role in facilitating trade and attracting and retaining globally mobile resources becomes ever more important in a globalising world.

Table 1: How Transport Impacts the Economy - Eddington Study

• Increasing **business efficiency**, through time savings and improved reliability for business traveller, freight and logistics operations.
• Increasing **business investment and innovation** by supporting economies of scale or new ways of working.
• Supporting **clusters and agglomerations** of economic activity. Transport improvements can expand labour market catchments, improve job matching, and facilitate business to business interactions. Transport's contribution to such effects is most significant within large, high-productivity urban areas (e.g. London in the UK)
• Improving the **efficient functioning of labour markets**, increasing labour market flexibility and the accessibility of jobs. Transport can facilitate geographic and employment mobility in response to shifting economic activity e.g. in response to the forces of globalisation, new technological opportunities, and rising part-time and female participation in the labour market. Nationally, transport improvements are unlikely to have a large effect on the employment rate, though may do so in some local circumstances.
• Increasing **competition** by opening up access to new markets. Transport improvements can allow businesses to trade over a wider area, increasing competitive pressure and providing consumers with more choice. Countries like Ireland are already well connected, so significant competition impacts are most likely to be felt from the integration of markets globally.
• Increasing **domestic and international trade** by reducing the costs of trading. Since 1960, falling transport costs have boosted the international trade of goods by 10-17.5 per cent, raising UK GDP by an estimated 2.5-4.4 per cent.
• Attracting **globally mobile activity** to by providing an attractive business environment and good quality of life. Such effects are of increasing importance but extremely difficult to quantify.

The SACTRA (Standing Advisory Committee for Trunk Road Assessment) report (1999) concluded that the theoretical links between transport improvements and economic activity to be strong. The SACTRA report found that there are number of important mechanisms through which transport can lead to increased economic activity:

- reorganisation or rationalisation of production, distribution and land use;
- effects on labour market catchment areas and hence on labour costs;
- increases in output resulting from lower costs of production;
- stimulation of inward investment;
- unlocking inaccessible sites for development; and
- triggering growth which in turn stimulates further growth

They conclude that interventions that reduce transport costs can boost economic performance as:

"*businesses can pass on the benefit of lower production costs to consumers in the form of lower prices, or they can implement further efficiency improvements by reorganising production and distribution. The economy can also benefit if lower transport costs help stimulate easier transfer between jobs, or greater competition among firms".*

Section 3: Measuring Transports Impact

3.0 Introduction

The role of public infrastructure in stimulating economic growth and development has been the subject of considerable research effort over many decades. A number of theoretical and empirical frameworks for analysing the range of variables that affect economic growth have been developed over this time.

Numerous theoretical and empirical papers have been written on the link between transport infrastructure and economic or productivity growth. This section presents a definition of infrastructure and an outline of the most common empirical models employed. The interpretations of the results of these studies are discussed in section 4.

3.1 Approaches to Assessing the Economic Impact of Transport

The contribution of transport infrastructure and transport policy has been measured or observed from various perspectives. These include:

- Effects on aggregate economic welfare (i.e. the sum of consumer and producer surplus), which is the focus of cost benefit analysis, as applied to policies or projects;
- Microeconomic (e.g. enterprise or household) level productivity effects; and
- Macroeconomic effects (e.g. contributions to GDP, investment or employment), and the spatial patterns of economic activity (Duncan, 2009).

The approach to quantifying of benefits and costs in a project appraisal is mainly a cost benefit analysis (CBA) method which measures direct effects of transport investment (i.e. time savings, user charges, operating costs, and externalities). Most European countries use a CBA approach to estimate economic returns from transport investment.

To date there is no agreed consensus about how indirect effects of infrastructure are treated. The most revealing evidence on this topic comes in the form of macro-econometric models that look at effects of transport investment on productivity or output growth. This is due to the difficulty in separating the indirect effects of the direct effects while avoiding double counting. Indirect effects can be transitory or permanent; they concern mainly distribution effects, economies of scale, change in location preferences, environmental effects and knowledge spillovers. These models are particularly useful when one considers the difficulty in measuring indirect effects that may be distorted by a combination of government intervention and market forces. These models are not without their pitfalls and challenges. These are explained further below.

Attempts at measuring the economic impact of transport investment have been made by many academics and researchers over the years. The approaches adopted have been influenced by the differing economic and environmental contexts of the analyses. For example, different studies may use very different data depending on the type of investment been considered, (road, rail, expenditure or stock etc). Very often the variables used will reflect more the type of data which is publicly available. The spatial effects captured range from local, regional, national to international effects.

3.3 Model Specifications

A number of economic specifications can be identified in the modelling of the effects of transport infrastructure investment. They are the Production Function approach (PFA), the Multivariate Approach (MA) and the Vector Auto Regressive (VAR) approach.

Production Function approach (PFA)

This method involves generating a static single-equation that regresses private output on private sector variables[2] and public capital. Public capital in this approach acts as an additional or technological input that affects private sector productivity.

The lack of public capital stock data for many Organisation for Economic Cooperation and Development (OECD) countries means that many of the academic empirical studies available focus on the United States. The majority of studies adopt this approach, which tries to measure the output elasticity of public capital by estimating a production function that includes public capital stock as an input. Aschauer produced a seminal paper that pioneered this approach in 1989 (Aschauer, 1989a). His work sparked a new wave of empirical investigation and debate that continues to this day.

Effects of public capital are interpreted as the elasticity of output with respect to public capital, assuming that an increase in the infrastructure stock enhances total factor productivity.

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[2] These variables include employment and non-residential private fixed capital stock

Multivariate approach

Following a wave of criticisms of the PFA approach, which is discussed in section 4 below, the research progressed to a multivariate approach. This method involves estimating two cost functions (some studies use a profit approach instead of cost). One equation shows that firms produce a certain level of output at a minimum cost, taking technological change, scale economies and input demand into account. The second equation shows public capital, which is assumed to be publically provided external to the firm but directly affects the firm's optimisation of output. Considering these two, the effect of public capital on output is measured by the reduction in production costs because of a rise in public capital. The signs of indirect effects on private inputs in the output of the model provide information about the nature of the relationships between inputs, something that was not possible in the production function approach.

Vector Autoregressive (VAR) approach

More recently, authors have adopted the Vector Autoregressive (VAR) Approach because it addresses the econometric concerns of previous approaches in this area in a more comprehensive manner. VAR models have become increasingly popular in recent decades. They are typically used to provide empirical evidence on the response of macroeconomic variables to various external impulses in order to discriminate between alternative theoretical models of the economy.

VARs models are dynamic systems of equations that examine the inter-relationships between economic variables, using minimal assumptions about the underlying structure of the economy. VARs are a system of equations in which dependent variables are regressed on lagged observations of all the variables in the system. They aim is to provide good statistical representations of the past interactions between variables letting, the data determine the model.

The elasticities and marginal products that are generated from the results of VAR models are not based on ceteris paribus assumptions, but instead, reflect the total accumulated long-term changes, direct and indirect, in each private sector variable due to an initial shock in public capital.

Section 4: Literature Review

4.0 Introduction

The link between infrastructure and economic growth has being debated for many years, and in the last few decades has produced a large body of literature. This review concentrates on the most influential papers on the subject and reviews some meta-analyses of empirical work in the area. We also include a brief summary of papers that have considered the Irish evidence.

4.1 The Relationship between Economic Growth and Public Capital Investment

Most economists and policy makers believe that public capital investment can enhance the productive capacity of an area by increasing the resources and productivity of existing assets (labour and private capital). Aschauer's 1989 paper kick started the debate following a significant decline in US productivity growth during the 1970s. Aschauer argued that the decline in productivity was precipitated by declining rates of public capital investment. He was one of the first researchers to use a production function approach for estimating these effects. He estimated an elasticity of output with respect to public infrastructure capital[3] in the United States between 1949 and 1985 of between 0.38 and 0.56, signifying that public infrastructure has positive direct and indirect effects on private sector output and productivity growth. Other researchers (Munnell 1990a) also suggested that public capital has a large impact on private sector output and productivity.

In Aschauer's formulation, the direct effect on private sector output arises from the availability of public capital to support private sector production – roads, public transport and airports allow the distribution of goods and services throughout national and international markets. The indirect effect evolves from the complementarity between private and public capital in private-sector productivity activity; an increase in the stock of public capital raises the return to private capital that, in turn, serves to spur the rate of expansion of the private sector capital stock.

While policy makers welcomed Aschauer's findings and used it as evidence to support public capital investment programmes, academic economists were less positive, due to concerns

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about the methodology adopted and particularly the choice of assumptions and model. These methodological concerns centred around three issues:

- The methodology was flawed, leading to spurious correlation;
- The wide range of estimates emerging from various studies rendered the coefficient suspect; and
- The causation assumption that public capital growth leads to output growth (i.e. increases in GDP) rather than the inverse.

Munnell (1992) addressed each of these concerns. The main methodological criticism was the risk of spurious correlation, which means that the data are not stationary but tend to drift over time, hiding the true relationship between the two variables. A solution proposed at the time was to specify the relationship in terms of first differences. This approach was unsatisfactory because the process of using first-differences removes the long-term relationship in the data, which is what we are interested in. Munnell identified this, and instead suggested that researchers test the variables for co-integration and adjust if co-integration is present. This meant that researchers should test not just whether the variables grow over time, but also whether they grow together over time and converge to their long-run relationship.

The second criticism was that the wide range of estimates of public capital's effect on output reduced the confidence one can have in the results. In Munnell's view, the fact that almost all estimates of the impact of public capital on private output were positive and statistically significant was a valid finding, with clear implications for public policy, particularly given that so much of public capital expenditure is designed to alleviate environmental problems or enhance quality of life, and consequently does not increase economic output as conventionally measured.

However, she also drew attention to a very important fact, which is that due to spatial spillovers, estimates of the productivity impact of public capital will vary depending on the geographical level of the analysis, and this itself can give rise to large variations in estimates. Due to leakages of benefits, the estimated impact of public capital decreases as the geographic focus narrows. Munnell also demonstrated that the size of estimates tended to be very similar for different levels of geographic analysis across studies.

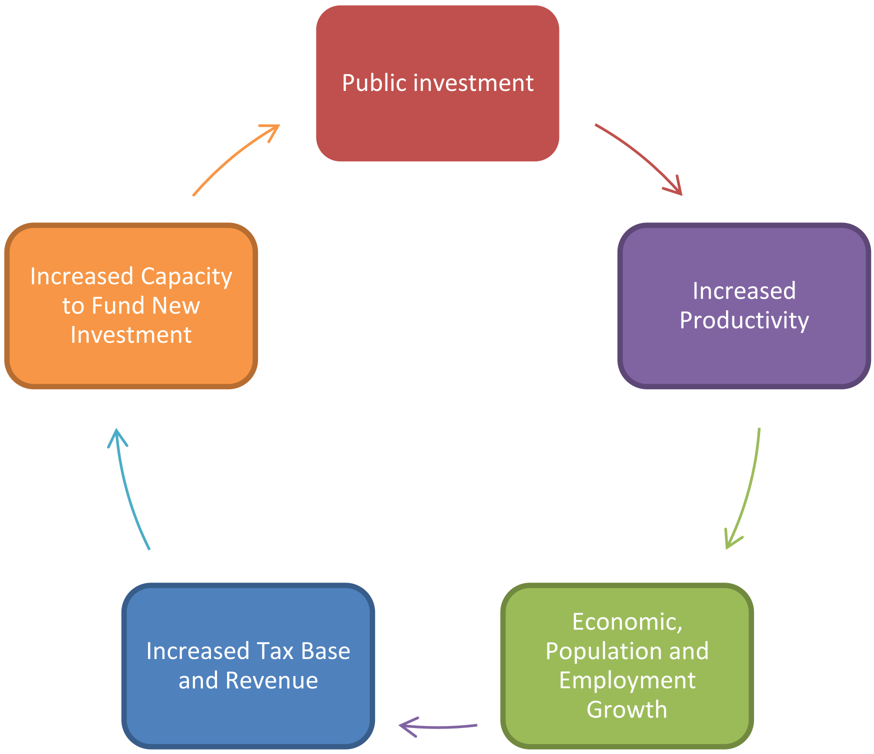
Finally, the third and most valid criticism was around the direction of the causation. Many critics of Aushauer's work felt that causation may run from growth in output to growth in public capital investment, rather than the other way around. These critics argued that capital investment, both private and public, goes hand in hand with, and is driven by, economic activity. Munnell (1992) was of the view that a mutual influence could exist without necessarily tainting the coefficient on public capital. In addition she re-estimated some of Ashauer's equations but only including the value of public capital at the beginning of the period, which foreclosed the possibility of any feedback effect of output growth on public capital investment. Even in these re-estimates, Munnell found that public capital continued to exhibit a large, positive and statistically significant effect on output. Munnell did, however, conclude that her findings were not a definitive answer to the question on the direction of the causation.

Munnell concluded that the size of the coefficients on public capital in Ascheaur's (1989a, 1989b, 1990) papers were too large to be credible and that further work was required on the causation issue in particular. However, she accepted the evidence that public capital infrastructure is a productive input that could have sizeable returns.

Elberts and Forarty (1987) and Eddington (2006) found that causation can run in both directions. However Bose and Haque (2005), in a study of mainly developing countries between 1970 and 1989, found evidence that the effects running from growth to subsequent public investment are stronger than the effects running from public investment to subsequent growth, contrary to Ascheaur's assumption.

Spoher et al. (2012) propose a virtuous cycle (Figure 1) to illustrate the relationship between infrastructure and growth. Under this conception, public investment in economic infrastructure leads to increased productivity in the private sector, which in turn leads to increased economic output. This increased economic output in turn leads to an increased tax base and tax revenues which create increased capacity to fund new infrastructure investment. This view echoes the views of Munnell , Elberts and Forarty (1987) and Eddington (2006), and seems a more realistic assessment of the causation issue.

Figure 2: Virtuous Cycle of Public Investment



Source: Spoher et al, 2012

In 1993, Finn followed Aschauer's approach to estimating returns to US government capital. She considered Ascheaur's findings to be somewhat unconvincing due to the size of the elasticities derived, and the fact that some public capital stocks were highly unlikely to make a direct positive contribution to output (e.g. hospitals, prisons etc.). This was particularly the case given that Ascheaur's estimates for public capital productivity were higher than some estimates of private capital productivity at the time.

Finn restricted her analysis to US highway capital, and found an elasticity of 0.16, which supported, but moderated, Ascheaur's findings. Finn also concluded that an average coefficient of 0.16 concealed large variances in the number depending on the time period. For example, between 1950 and 1969, highway capital growth contributed to 22% of output growth, whereas in the 1970 to 1989 period, highway capital growth contributed to 6% of output growth. The literature suggests this could be due to the extent to which public investment in infrastructure is economically efficient. In other words, the impacts may differ across time-periods because the economic effects of infrastructure investments are subject to the amount and quality of infrastructure in place prior to investment.

Following Finn’s (1993) contribution to the debate, Nadiri and Mamuneas (1996) provided an analysis of the impacts of US highway capital which supported the theory that highway investment contributes significantly to output growth. Their findings also echo Finn’s finding that output elasticities fell during the latter part of the period under consideration. Specifically, they concluded that the output elasticity with respect to capital averaged 0.08 over 1950 to 1991, but declined from 0.15 at the outset to 0.03 at the end of the period. This growth is attributed to reductions in costs and increases in profitability for the transport-intensive sectors.

Towards the end of the 1990s, Fernald (1999) produced a paper which suggested that a construction boom in America substantially boosted productivity in the 1950s and 1960s. He proposed that this boom offered a one-time boost to the level of productivity, rather than a path to continuing rapid growth in productivity.

To reinforce this idea, Fernald drew on Hulten’s (1996) findings that the building of “*the interstate network may have been very productive, but building a second interstate system may not be*". A wide range of factors may have caused the slowdown in US productivity in the 1970s. Public investment in roads was a contributing factor but only for industries reliant on vehicles: “*sectors with greater vehicle intensities tended to experience larger productivity slowdowns after 1973*”.

Fernald’s conclusion is that changes in road capital growth are associated with larger changes in productivity growth in industries that are relatively vehicle-intensive. This result also supports the notion that correlation between aggregate productivity and infrastructure reflects causation from changes in road stock to changes in productivity. This finding also sheds some light on the previous work by Finn (1993) and Nadiri and Mamuneas (1996), which found a reduction in output elasticities for highway capital growth in the US in the latter part of the period under consideration (1950s-1980s).

In 1999, SACTRA (the Standing Advisory Committee for Trunk Road Assessment) in the UK published one of the most influential pieces of research on the economic impact of transport investment. Its report considered a range of issues, but considered specifically the question “*do transport improvements lead to increased economic activity*?” Their conclusions on the size and nature of the effects of transport cost changes is that effects do transpire but on a lesser scale than has been claimed and that in general, any contribution of transport to the sustainable rate of economic growth of a mature economy, with well-developed transport systems, is likely to be modest. This finding was strengthened by the conclusions of many texts including Sturm and de Haan (1995).

SACTRA found that direct statistical and case-study evidence of the size and nature of the economic effects of transport cost changes was limited, and that there was no consensus in the evidence that does exist on the size of the economic effects of transport. It also found that, despite strong theoretical evidence, no economic effects can be guaranteed, and the effects of transport are strongly dependent on specific local circumstances and conditions.

Along with SACTRA and Fernald, Duggal et al. (1999) published a paper suggesting that the marginal product is initially productive to a point after which the marginal returns are decreasing. In terms of infrastructure investment, this means that there is a point at which further investment in infrastructure is less productive than investments elsewhere (health, education, etc) or than a reduction in taxes used to fund investments.

Following these papers by Bougheas, Demetriades and Mamuneas (2000) and De la Fuente (2000) suggested that the relationship between infrastructure and growth is non-monotonic; i.e. a positive relationship between economic growth and infrastructure cannot always be guaranteed, there may be an optimal stock of infrastructure beyond which further additions of infrastructure negatively affect growth. Thus, countries with a lower stock of infrastructure will have the highest return to additional infrastructure, while those with a stock of infrastructure that is above the growth maximising level will actually grow slower with more infrastructure investment, because investment would be more economically efficient in sectors where there are more capacity constraints. These findings were reinforced in an Irish context in ESRI Mid-Term evaluation of NDP 2000-2006 (2003).

Shirley and Winston (2004) provided an interesting addition to the debate more recently that focuses on some of the productivity impacts of roads investment. They found that a large positive effect from highway investment through savings on inventories, as transport intensive industries could make deliveries more speedily and reliably. This equated to a rate of return on highway investments in the 1970s of 17.6 per cent, which fell to 4.9 per cent in the 1980s and 1 per cent in the 1990s. Evidence of diminishing marginal returns of highway investment is also found in other research that considered highway investment, discussed above (Finn 1993, Fernald 1999, Nadiri and Mamuneas 1996).

In 2004, the International Monetary Fund published an analysis using internationally comparable annual capital stock estimates for 22 OECD countries for the period 1960–2001 (Kamps, 2004). The regression results confirmed previous findings in the literature using the production function approach and showed that the elasticity of output with respect to public capital is positive and statistically significant, and quite large for most countries. Based on a simple panel data model, this study found the elasticity of output with respect to public capital to be 0.2 on average for OECD countries.

The U.S. evidence seems to indicate that there was a step-change effect of completing the interstate highway system in the post-war period and a continuation of the massive road-building programme would not then have been a path to faster total factor productivity (Finn 1993, Fernald 1999, Nadiri and Mamuneas 1996, Shirley and Winston 2004).

Some of these results are echoed in European research on infrastructure investment. Once again, the lack of consensus on the issue is highlighted in three prominent results. Firstly a study by Destefanis and Sena (2005) considered the elasticity of output with respect to infrastructure capital in Italian regions with low initial stock such as the Mezzogiorno. It found high output elasticities for the period 1970-1998. In contrast to this study, Combes and Lafourcade (2005) studied the large decline in French freight transport costs between 1978 and 1998. Their paper shows that this primarily resulted from deregulation of trucking and technological improvement in vehicles rather than new roads, even though the road network expanded by about 9% and its quality was significantly improved.

Kopp (2005) considered the aggregated productivity effects of road investment in 13 Western European countries. He found that road infrastructure has positive macroeconomic productivity effects, although the implied rate of return for many countries was low, at around 5%. However, the author concluded that a low rate of return may not necessarily arise from too high a level of investment, but could be due to a misallocation at the local level. The author points to the very unequal distribution of transport demand over time and space, implying an important role for project-level analysis (i.e. CBA) in identifying projects of social benefit.

Britain has long been a leader in appraising transport interventions both, at a micro and macro level. Perhaps the most significant piece of research on the issue in Britain was the Eddington Transport Study, produced by Sir Robert Eddington in 2006 for the UK Department of Transport (*The Eddington Transport Study, 2006*). This report addressed key transport issues, specifically the question "*How transport can contribute to economic success?*"

Eddington accepted that transport cannot create growth itself, rather it is a tool that can improve productivity when other factors in play are at the right stage. He demonstrated that history has shown that transport has played a major part in economic development. Eddington's central conclusion was that transport supports the economy and that:

"a comprehensive and high-performing transport system is an important enabler of sustained economic prosperity: a 5 per cent reduction in travel time for all business and freight travel on the roads could generate around £2.5 billion of cost savings – some 0.2 per cent of GDP".

Melo et al (2011) conducted a meta-analysis of productivity in transport infrastructure investment using 33 studies and 563 coefficient estimates. Across the 563 coefficient estimates reviewed they found a mean output elasticity of transport infrastructure investment of 0.06, but with considerable variation (standard deviation of 0.288).

This paper considered a number of the themes that have emerged from this body of research, and made a number of important conclusions:

1. Intermediate-run (0.08) and long-run (0.07) elasticities are significantly higher than short-run elasticities (0.04), suggesting a strong time-lag for the effects of transport to fully work through the economy;
2. Estimates for the US and other countries are larger than EU countries. Output elasticity for US and other countries was 0.08 and 0.07 respectively, whereas for EU countries the value was 0.04;

3. Meaningful differences exist between industry groups. Manufacturing for example has a higher value than for all sectors, 0.082 and 0.065 respectively, and sectors like services or construction have very low elasticity values;
4. Roads have the highest elasticities (0.09) when compared to other modes of transport including airports, port/ferries and railways, 0.03, 0.07 and 0.04 respectively.
5. Physical measures of transport are associated with higher average output elasticities than monetary measures (0.108 against 0.046 respectively).

As mentioned above Melo et al found no evidence that country income levels affect elasticity estimates, meaning there was no support for the view that as transport networks become larger, the marginal effect of a new addition becomes gradually smaller due to diminishing marginal returns to transport. However their results do show that the type of study and approach taken can in part explain the variation in existing empirical evidence.

The discussion of the texts demonstrates the plethora of empirical arguments on the topic. While there is no consensus among the authors on the scale and magnitude of these effects, a lot of the variation in results can arise because of differences in spatial aggregation, the type of data used and model specification.

Spatial aggregation is important in determining the magnitude of elasticity, as mentioned in the analysis of Munnell (1992) earlier in this chapter. Elasticities tend to be smaller for studies at a local level than at a national or international level. Researchers find it difficult to capture leakages as the spatial level narrows from nations to counties to cities.

The time period considered has a large effect on the results of the research, with a number of American studies on the interstate highways reinforcing this (Finn 1993; Nadiri and Mamuneas 1996; Fernald 1999).

Evidence from the papers considered show that models that use panel data or cross sectional data[4] tend to find relatively smaller elasticities, implying lower short-run effects from transport investment.

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[4] It is accepted that studies which use time series data produce short run elasticities and those that use cross-sectional data produce long run elasticities (Baltagi, 2008)

While these issues are not omnipresent in the papers considered there is broad agreement that a number of these factors affect the results (O'Fallon, 2003; Ahn, S. and P. Hemmings 2000).

The majority of papers considered in this and other reviews (Melo, 2012; Makhoulfi, 2011; Straub, 2008; Kopp, 2005) indicate that there is a positive relationship between infrastructure capital stock and economic growth. Productivity increases arise because transport investment is seen to enhance the productivity of different inputs (i.e. labour and private capital).

It is clear also that the level of spatial aggregation, type of capital stock considered and country characteristics and time span adopted in the analyses have significant influences on the magnitude of results reported. Section 4.4 will present a summary of the results across a large number of studies.

4.2 The Two-Way Road Effect

Some papers on the link between transport infrastructure investment and economic growth in developed countries have drawn attention to the "two way road" phenomenon (SACTRA, 1999 and Goodwin, 2002). For example, a transport improvement leads some firms to move away from one location to another where the prices of their products remain competitive in both markets. Developments in the new economic geography literature (Fujita et al, 1999; Fujita and Thisse, 2002) also hypothesise that transport improvements could encourage centralisation as well as the dispersion of economic activity, depending primarily on the level of initial transport costs, the level of reduction in transport costs, and the extent of agglomeration economies (e.g. Venables and Gasiorek, 1999).

Another potential advantage of agglomeration is that a denser labour market permits better matching of skills and supplies and encourages the development of a pool of expertise. Consequently, bigger cities tend to have higher labour productivity so that transport improvements that raise the effective size of a city's labour market lead to a positive productivity externality for the city (Crafts and Leunig 2005, Rice and Venables 2004).

4.3 Research Considering Transport and Irish Economic Growth

Very few authors have examined these issues with regard to the Irish case. Kavanagh (1997) estimates aggregate production functions, an approach similar to Ashauer (1989), for private sector output. Her results produce a statistically insignificant coefficient for public capital, indicating no support for idea that public capital has a positive impact on private sector output. This implies that a lack of infrastructure would not result in lower levels of output compared to a situation where there is adequate infrastructure. However, these findings did not align with real evidence of increasing congestion and travel times on Irish roads at the time, which suggested that infrastructure investment provided economic benefits in areas where travel times and congestion had increased.

Denny and Guiomard (1997) found unrealistically high estimates of output elasticities (0.93 to 6.3) of manufacturing and public capital components of the Irish gross capital stock over a 10-year period (1985-1994). Morgenroth (ESRI, 2003) found significant positive output elasticities for Irish infrastructure investment. He found that, while roads infrastructure has a direct positive impact on output and consequently a positive return, water and sewerage infrastructure did not appear to have such an effect. This might reflect the fact that water and sewerage infrastructure has an indirect effect through improvements in quality of life and is therefore more difficult to capture with conventional modelling techniques.

Morgenroth (2003) found that road infrastructure elasticities were higher for the manufacturing sector than the services sector. He also calculated the return that can be expected from public investment, i.e. the marginal product, dependent on levels of existing capital stock. He found that at no point did the returns to road infrastructure exceed those of private capital, which makes intuitive sense. In fact one of the criticisms of Aschauer's original work was that it implied returns to public capital exceeded those to private capital by some margin.

Morgenroth found that the returns over a long period were no higher than the long-run interest rate, but that during the 1990s they rose very substantially to an average of 30 per cent. While these returns appear high they point to the severe infrastructure deficit which was present in Ireland at the time, and which put a constraint on the economy as a whole. Indeed it is well known that when investments remove bottlenecks the return is very substantial as such investments not only have a direct return, but they increase the return of the existing infrastructure.

Some international texts consider Ireland in their analyses but very few find a statistically significant result (Sutherland et al. 2009).

Some of the most recent literature suggests that the efficiency with which existing transport networks are used is at least as important as the underlying level of investment (e.g. Eddington 2006). Therefore, in economies such as Ireland, with relatively well developed transport networks, it can no longer be expected that the impacts of transport improvements will be transformational. It may be more the case that improvements can have important impacts by releasing constraints on the economy.

4.4 Review of Meta-analyses

Given the large number of studies in this area it is no surprise that a number of meta-analyses have been conducted. Meta-analyses seek to crystallise similarities and contrasts in the results and to identify characteristics of the studies which affect the findings. Examining the meta-analyses can provide a greater understanding of the variety of results of studies examining the impact of infrastructure on output. In this section we review two meta-analyses, and combine their results into a consolidated table (Table 2, Appendix). The meta-analyses considered are a A.El Makhloufi (2011) and Melo et al. (2012)[5].

El Makhloufi's analysis reviewed 109 papers,[6] covering working papers, published papers and unpublished papers. All papers considered the impact of public capital investment on economic output. Some of the papers restricted public capital to just transport, although others included other types of economic infrastructure such as water supply and sewage systems as well as transport.

For this review of El Makhloufi's meta-analysis we have only included published papers that were considered in the literature review above to increase confidence in the reported elasticities.

[5] In some cases both papers reported slightly different elasticities for the same paper. The authors decided to use Melo et al. estimates because the paper had been published.

[6] At the time of writing, El Makhloufi (2011) was a work in progress. The author has indicated that although he was continuing to make changes to the empirical model the other parts of the paper (i.e. theoretical and data) were not likely to change.

El Makhloufi found that the output elasticity of public capital shows considerable variation across studies. He identified the type of public capital, the level of aggregation, country type and the choice of economic model as issues that can cause variation in the results presented.

The Melo et al. (2012) meta-analysis aimed to improve the understanding of the impacts of transport on economic growth, given the lack of ambiguous results among studies addressing the question. The mean output elasticity with respect to transport investment in the Melo meta-analysis was 0.06. They found that differences in study characteristics help explain the variation across empirical results. Methodological problems related to spurious regressions, omitted variable bias, and the endogeneity[7] of transport infrastructure were found to affect the magnitude of output elasticities. All 33 of the papers considered in this meta-analysis are included this review. Most studies use data from the 1970s and the 1980s, arising from the wave of empirical research in the area in the 1990s.

Table 2 (Appendix) lists the studies considered in the consolidated meta-analysis. For each study, the table shows the author, publication year, number of observations, and the mean and range of the estimates of elasticity of output with respect to transport capital. The studies are listed in reverse chronological order depending on publication date.

Table 2 contains 62 empirical studies which have produced 387 estimates. While this is not a definitive list of papers in this field, it represents a collection of studies often cited in academic and public policy papers, and which are the most influential texts in the field.

Chart 1 below shows a frequency distribution of the mean output elasticities from the studies included in the meta-analyses. Frequency bins of 0.05 are used for clarity in the chart. The values on top of the bars represent the number of elasticities estimates generated in the respective studies (i.e. the first bar shows that 4 studies in the analysis estimated a mean elasticity of less than -0.1 and these studies derived 14 elasticities).

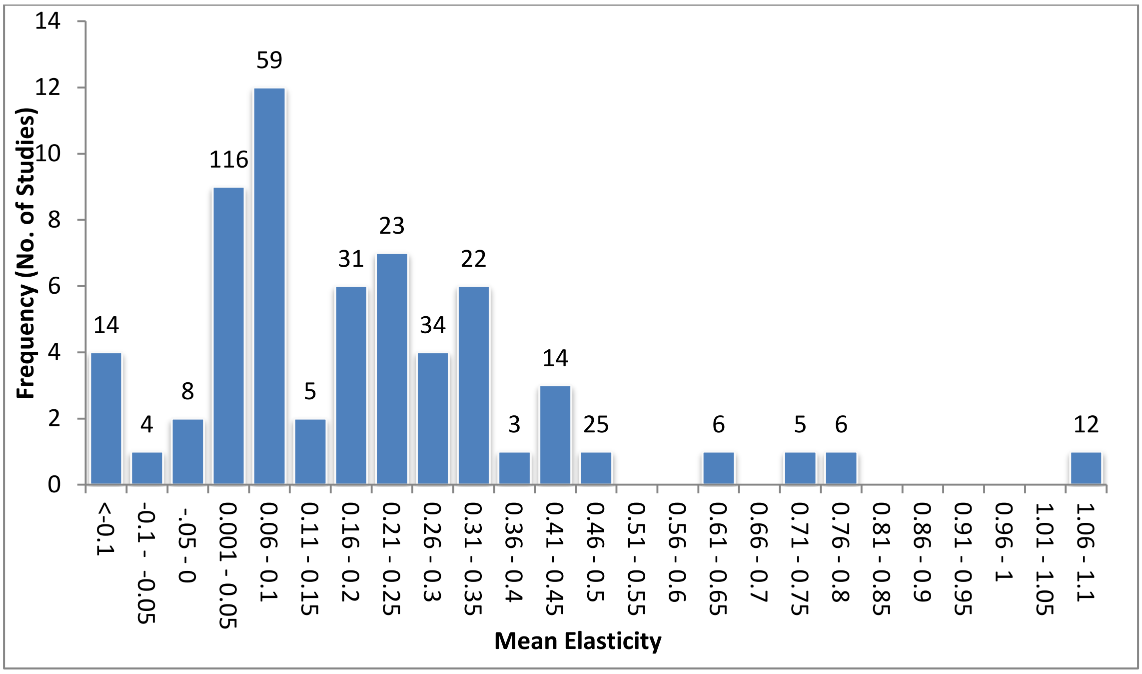
The two most frequently reported ranges for mean elasticities are 0 to 0.05, and 0.06 to 0.1. There are 7 negative values in the analysis, with 55 studies arriving at a positive mean elasticity. The range of values that are reported most frequently (0 to 0.05 and 0.06 to 0.1)

[7] Correlation between the variable and the error term.

have the largest number of observed elasticities associated with them, 116 and 59 respectively, representing 45% of the total elasticity estimates.

The majority of papers that consider this question derive fewer than 10 observations. Of the 62 papers considered, 10 papers have 10 or more observations all of which are positive[8]. As can be seen from the chart the vast majority of studies report positive output elasticities.

Chart 1: Frequency Distribution of Estimates of Elasticity of Output with Respect to Infrastructure Investment



Source: EFEU

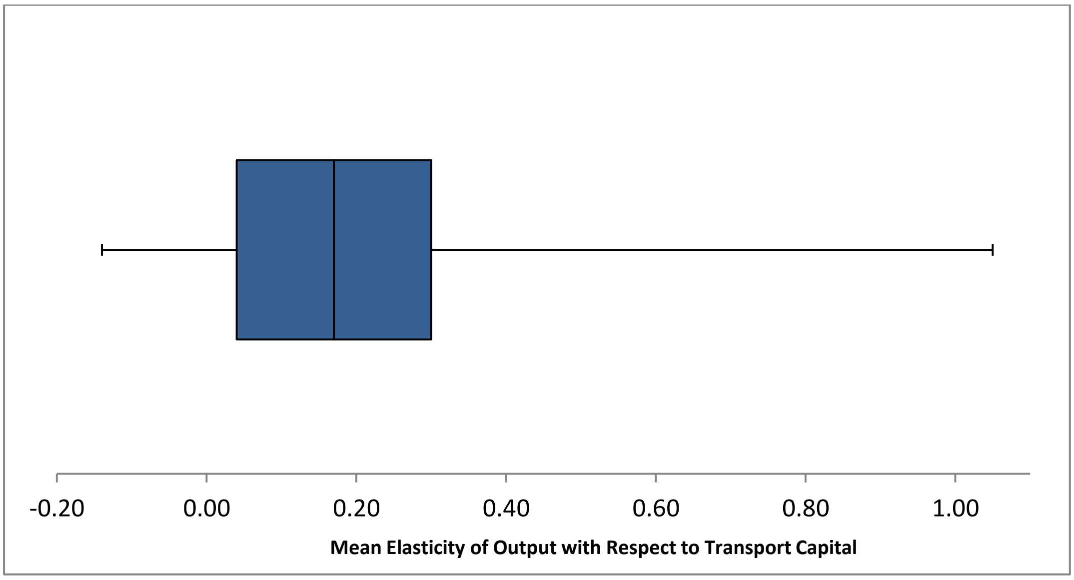
When all means are considered, the mean of the mean is 0.20. This result suggests the transport investment has a positive effect on growth.

Chart 2 presents the same data in box-and-whisker plot form. In Chart 2 the outer bounds of the box represent the 25th and 75th percentiles[9], which are 0.05 and 0.30 respectively. The median elasticity is 0.18. The long whisker to the right indicates the data are skewed towards positive elasticities.

[8] Economic intuition would suggest that more observations make the average more statistically accurate because different specifications can test the robustness of the elasticities arrived at in each model.

[9] The 25th percentile (or quartile) is the value below which 25% of the observations may be found.

Chart 2: Box-and-Whisker Plot of Elasticities with respect to Output



Source: EFEU

The two charts above presented data from 62 studies that produced 387 estimates. The evidence from the two meta-analyses indicates the majority of elasticities derived from empirical models that consider the relationship between output and transport investment are positive. The meta-analyses also show that 75% of studies reported mean elasticities of 0.05 or greater, with a median elasticity across all the studies of 0.18, implying that for each 1% change in public capital, output responds by 0.18%.

A small proportion of studies reported negative elasticities, suggesting there may be circumstances where transport investment can have a negative impact on growth.

Section 5: Summary and Conclusions

Increases in transport investment and advances in transport technology have long been associated with increases in economic activity and output. The development of modern economies can be traced through the emergence of enhancements to transport capital, from the first international shipping routes and ports, to the development of canals systems, railways, urban mass transit systems and airports. Changes in economic output and changes in transport demand have been found to be positively correlated over time in many countries. The German economist Weber, as far back as 1928, identified transport as a central influence on the location and efficiency of economic activities.

There has been much theoretical research into the mechanisms through which transport impacts the economy, and there is now a good understanding of the many ways, both direct and indirect, through which transport affects economic activity. The theory seems to coalesce around the following mechanisms:

- reorganisation or rationalisation of production, distribution and land use, including through supporting economies of scale and unlocking inaccessible sites for development;
- effects on labour market catchment areas and hence on labour costs;
- increases in output resulting from lower costs of production through time savings and improved reliability for business travellers, freight and logistics;
- supporting clusters and agglomeration of economic activity, improving job matching and business to business interactions, leading to lower costs and innovation;
- stimulation of inward investment, including through provision of an attractive business environment and good quality of life; and
- increased domestic and international trade through reducing the costs of trade.

As well as increasing output and income levels (Barro and Sala-i-Martin, 1995), transport investment can also increase growth rates, according to some variants of endogenous growth theory. This link is established through the effects of transport infrastructure investment on urban form and city size, and the resulting agglomeration economies (Lucas, 1988; Black and Henderson, 1997; Lucas, 2001; Lucas and Rossi-Hansberg, 2002).

The rationale for state intervention in the provision of transport is well understood and derives from:

- the scale economies which characterise the fixed asset components of transport (e.g. railway infrastructure); and
- the externalities generated through the operation of transport services (congestion, pollution etc.).

The issue of the effect of public capital in general, and transport investment in particular, on economic output has been the subject of much academic debate, particularly over the last three decades. The first generation of empirical studies, led by Ascheaur (1989), found that public infrastructure had a very large impact on private sector output and productivity growth. These findings, although accepted with enthusiasm by policy makers, were criticised on a number of fronts. The first wave of empirical papers on the issue produced a wide range of estimates, which in itself rendered the coefficients suspect, and in addition some of the estimates were perceived to be too large to be credible. Also, the findings were criticised for the assumption around the direction of causality, i.e. that public capital growth leads to output growth rather than vice versa.

These issues were addressed by subsequent researchers building on the model developed by Ascheaur. On the causation issue Munnell (1992) believed a mutual influence could exist without necessarily tainting the coefficient on public capital. She re-estimated some of Ashauer's equation in a manner that foreclosed the possibility of any feedback effect of output growth on public capital investment, and found that public capital continued to exhibit a large, positive and statistically significant effect on output. Other researchers also found that that a feedback loop existed, and that causation could run in both directions. The balance of opinion on this issue seems to follow Spoher et al (2012) who propose a virtuous cycle in which public investment in infrastructure giving rise to economic growth, which in turn generates an increased tax base and tax revenues which in turn generates increased capacity to fund new investment.

On the issue of the size and variety of estimates, the more recent research and meta-analyses has uncovered themes in the empirical work which have greatly helped our understanding of the determinants of the size of the impact of transport on the economy, and can explain much of the variation in the empirical evidence. These variations tend to relate to model specifications, level of disaggregation in the data, geographic area considered, and the time period considered.

Researchers have shown that estimates of the productivity impact of pubic capital vary depending on the geographical level of analysis, due to spatial spillovers. The larger the geographical area being considered the larger the elasticities – studies for the US typically report larger elasticities than studies for European countries, for example, as more spatial spillovers are captured in the analysis.

Researchers have also found that the economic effects of transport take time to be fully reflected in economic output, which is echoed in the fact that long-run and cross-sectional elasticities are significantly higher than short-run elasticities.

Meaningful differences also exist between sectors, with higher elasticities in more transport intensive industries. The unit of measurement of transport also matters, with monetary measures of transport infrastructure as opposed to physical measures tending to produce lower elasticity values.

The evidence on whether there are diminishing returns to transport infrastructure is ambiguous. Many researchers have found evidence of diminishing marginal returns, particularly to highway investment in US studies. Other researchers have found that the relationship between infrastructure and growth is non-monotonic, i.e. there may be an optimal stock of infrastructure beyond which further additions negatively affect growth. Thus, countries with a lower stock of infrastructure will have the highest return to infrastructure, while those with a stock of infrastructure that is above the growth maximising level will actually grow slower with more infrastructure investment, because investment would be more economically efficient in sectors that are capacity constrained.

However, in their meta-analysis Melo et al (2011) found no statistically significant difference in elasticity estimates across country income levels. They postulated on the basis of this that higher marginal returns to transport investment in low income countries, due to the law of diminishing returns, could be offset by the small connectivity benefits that accrue in very sparse and meagre transport networks in such countries. A similar but opposite effect would operate in high income countries.

Morgenroth (2003) found that the returns to road infrastructure in Ireland over a long period were no higher than the long-run interest rate, but that during the 1990s they rose to an average of 30%. At this time there were significant capacity constraints in transport in Ireland, and this implies that returns can increase when bottlenecks are relieved even in developed networks, as such investments tap into significant network demand and benefits.

The debate on diminishing marginal returns to transport, in the context of an advanced network such as Ireland's, only serves to underline the importance of having a rigorous individual project appraisal and selection process, not just in the transport sector but in other public infrastructure sectors also.

Evidence suggests that public capital plays a significant role in economic growth. When we turn to the size of the elasticity of output with respect to transport investment, the majority of studies reviewed (55 or 85%) found a positive elasticity, and of those that found a negative elasticity, only two papers found a range which is consistently below zero for all observations.

However the size of the estimated elasticities has come down over time as methodological approaches have evolved and the econometrical models have been refined.

The Melo meta-analysis reported a mean elasticity of output with respect to transport of 0.06, meaning that for every 1% change in transport capital, output responds by 0.06%. Across both the Melo and El Makhloufi meta-analyses, covering 62 empirical studies, there was a mean of 0.20, with 75% of studies reporting a mean elasticity of 0.05 or above.

Appendix

Table 2: Collection of studies considered for analysis

No	Author	Year	Number of estimates	Mean	Minimum	Maximum
1	Pereira and Andraz	2010	4	0.11	-0.800	0.800
2	Abdih and Joutz	2008	3	0.38	0.130	0.610
3	Jiwattanakulpaisarn	2008	48	0.01	-0.014	-0.039
4	Morenao, Lopez-Bazo	2007	3	0.06	0.057	0.058
5	Ozbay et al.	2007	8	0.08	0.017	0.206
6	Delgado and Alvarez	2007	18	0.00	-0.002	0.017
7	Boopen	2006	16	0.09	0.000	0.301
8	Cantos et al.	2005	10	0.24	-0.187	0.211
9	Everaert and Heylen	2004	1	0.31	0.310	0.310
10	Albala-Bertrand and Mamatzakis	2004	3	0.03	-0.340	0.390
11	Kamps	2004	25	0.45	-0.560	1.260
12	Everaert	2003	1	0.14	0.140	0.140
13	Lighart	2002	2	0.28	0.200	0.360
14	Pereira	2001	3	0.18	0.020	0.260
15	Boscá et al.	2000	2	0.09	0.080	0.090
16	Canning	2000	3	0.32	-0.050	0.174
17	Stephan	2000	4	0.31	0.110	0.650
18	Canning and Bennathan	2000	7	0.06	0.003	0.134
19	Demetriades and Mamuneas	2000	12	1.06	2.060	0.360
20	Bonaglia et al.	2000	25	0.00	-1.960	1.001
21	Sturm et al.	1999	1	0.06	0.060	0.060

22	Pereria and Roca	1999	3	0.42	-0.310	1.080
23	Batina	1998	6	0.80	0.200	0.160
24	Gambel et al.	1997	4	-0.13	-0.790	0.180
25	Prud'Homme	1996	1	0.08	0.080	0.080
26	Boarnet	1996	2	0.26	0.236	0.300
27	Garcia-Milá et al.	1996	6	0.09	-0.058	0.576
28	De le Fuente and Vives	1995	1	0.21	0.210	0.210
29	Holtz-Eakin and Schwab	1995	2	0.05	0.050	0.050
30	Momaw et al.	1995	3	0.24	0.070	0.370
31	Sturm and De Hann	1995	5	0.72	0.260	1.150
32	Baltagi And Pinnoi	1995	9	0.07	0.020	0.160
33	Nadir and Mamuneas	1994	3	-0.15	-0.210	-0.110
34	Otto and Voss	1994	3	0.34	0.170	0.460
35	Cullison	1993	1	0.08	0.080	0.080
36	Finn	1993	1	0.16	0.158	0.158
37	Mas et al.	1993	3	0.17	0.070	0.240
38	Evans and Karras	1993	4	-0.08	-0.190	0.040
39	Fernald	1993	6	0.64	0.000	1.400
40	Johansson and Karlsson	1993	20	0.20	0.004	0.062
41	McGuire	1992	1	0.24	0.240	0.240
42	Pinnoi	1992	3	-0.04	-0.110	0.090
43	Conrad and Seitz	1992	5	-0.11	-0.270	-0.030
44	Garcia-Milá and McGuire	1992	5	0.05	0.044	0.045
45	Duffy-Deno and Eberts	1991	1	0.08	0.080	0.080
46	Biehl	1991	1	0.20	0.200	0.200
47	Duffy-Deno	1991	1	0.23	0.230	0.230

48	Hulten and Schwab	1991	2	-0.15	-0.369	0.072
49	Morrison and Schwartz	1991	3	0.02	-0.200	0.390
50	Tatom	1991	4	0.07	-0.010	0.140
51	Eisner	1991	4	0.22	0.170	0.270
52	Lynde and Richmond	1991	5	-0.04	-0.450	0.200
53	Ford and Poret	1991	8	0.43	0.290	0.620
54	Merriman	1990	3	0.42	0.200	0.590
55	Munnell	1990	4	0.28	0.140	0.490
56	Andersson et al.	1990	10	0.02	-0.006	0.045
57	Aschauer	1990	26	0.28	0.220	0.340
58	Aschauer	1989	8	0.35	0.060	0.740
59	Holtz-Eakin et al.	1988	3	0.20	-0.020	0.390
60	Deno	1988	3	0.32	0.062	0.571
61	Coata et al.	1987	3	0.22	0.190	0.260
62	Elberts	1986	2	0.04	0.040	0.040

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