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OPTIONS FOR BENCHMARKING INFRASTRUCTURE PERFORMANCE

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ABSTRACT/RESUMÉ

Options for benchmarking infrastructure performance

Three main approaches can be used to assess infrastructure performance. The first employs macro-econometric techniques to estimate the impact of the existing infrastructure capital stock on growth and to infer its growth-maximising level. This approach neglects the impact of infrastructure on some dimensions of social welfare, such as pollution. The second relies on *ex-ante* or *ex-post* cost-benefit analyses of infrastructure projects. These take into account desirable and undesirable outcomes and provide thus a welfare perspective, but this approach would not allow comparing the performance of the existing infrastructure stock. A third approach aims at benchmarking the social efficiency of infrastructure service provision based on the existing capital stock taking into account positive and negative externalities. This paper analyses the challenges in implementing these approaches.

JEL classification codes: H41; H54; D61; D62

Keywords: Infrastructure; efficiency; cost-benefit analysis

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Options pour évaluer la performance des infrastructures

Trois types de méthodes peuvent être utilisés pour évaluer la performance des infrastructures. Le premier suppose la mise en œuvre de techniques macro-économétriques permettant d'estimer l'impact du stock d'infrastructures existant sur la croissance pour en déduire son potentiel de maximisation de la croissance. Cette méthode ne prend pas en compte l'impact des infrastructures sur certains aspects du bien-être social, la pollution par exemple. Le deuxième repose sur des analyses coûts-avantages des projets d'infrastructures effectuées *a priori* ou *a posteriori*. Cette méthode permet de prendre en compte les externalités souhaitables aussi bien que non souhaitables des projets et permet donc de se placer dans la perspective du bien-être, mais cette méthode ne permet pas de comparer les performances des stocks d'infrastructures existants. Enfin, il existe une troisième méthode qui vise à étalonner l'efficience sociale de la prestation de services à partir du stock existant tout en prenant en compte les externalités positives et négatives. Les difficultés inhérentes à la mise en œuvre de ces trois méthodes sont examinées dans ce document de travail.

Classification JEL : H41 ; H54 ; D61 ; D62

Mots clés : Infrastructures ; efficacité ; analyse couts-bénéfices

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OPTIONS FOR BENCHMARKING INFRASTRUCTURE PERFORMANCE

by Mauro Pisu, Peter Hoeller and Isabelle Joumard[1]

1. Introduction

The contribution of infrastructure to the economy is large. One indication is provided by the value added of entire network industries. They account for a considerable share of GDP. On average in the OECD, the share of transport and storage in GDP is 4.5%, that of electricity, gas and water supply 2.5% and that of post and telecommunications 2.2%.[2] Network industries account for between one tenth and one quarter of economy-wide investment. However, more spending should not be confused with better outcomes as the size of network industries says little about their impacts on welfare. Infrastructure and their associated services generate multiple outcomes, such as time saved, improved connectivity or network effects, but also congestion, pollution and other environmental impacts, many of which are not included in the National Accounts as they are difficult to measure. Outputs are often taken as proxies for outcomes. Taking energy as an example, a reliable supply of energy to firms and households can be deemed a desirable outcome, but energy consumption also generates pollution, unsustainable use of natural resources and other undesirable environmental effects impinging negatively on welfare. Thus, any comprehensive performance measure must take into account the different outcomes whether desirable or undesirable and relate them to the various inputs.

The aim of this paper is to provide an overview of different approaches to benchmark infrastructure performance. It discusses the options, data requirements and challenges they involve. A first approach is based on macroeconomic data. Studies falling within this category have mostly focused on the infrastructure capital stock and its effects on growth. Albeit useful, this approach has limitations as it neglects those outputs that even if not affecting GDP growth impinge on welfare. Many of these outputs are externalities, which are poorly or not at all captured by the National Accounts. A second approach assesses new infrastructure projects rather than the existing stock, relying on *ex-ante* cost-benefit analysis (CBA) and *ex-post* project evaluations. These techniques aim at evaluating all possible outcomes of infrastructure and therefore their impact on welfare, but cannot provide an overall view of the performance of existing infrastructure. In this approach, performance is typically measured by the social rate of return of infrastructure projects. A third approach focuses on the existing infrastructure stock and measures its social efficiency *via*, for instance, Data Envelopment Analysis taking into account desirable and undesirable infrastructure outputs.

The road map for the paper is as follows. The next section reviews the different approaches that can be used to assess infrastructure performance. The third section provides an overview of countries' experience with infrastructure benchmarking. The fourth section provides concluding remarks.

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2. The available data do not permit a finer disaggregation of infrastructure sectors.

2. Possible approaches to infrastructure benchmarking

This section explores three approaches to benchmark infrastructure.

2.1. Benchmarking based on growth contributions

The bulk of studies of infrastructure performance has concentrated on the impact of the infrastructure capital stock on growth. Recent OECD work (Sutherland *et al*., 2011 and Égert *et al*., 2009) on this subject came to the following main conclusions:[3]

- The impact of infrastructure on output is difficult to pin down and the direction of causality hard to determine. However, there is some evidence that infrastructure investment has positive effects that go beyond the impact to be expected from a larger overall capital stock. Moreover, the marginal benefits of additional investments in mature networks are often low, which implies that infrastructure projects need to be carefully evaluated.

- Infrastructure investment appears to have a non-linear effect with a stronger long-term effect on growth at lower levels of provision. There is some evidence suggesting episodes of both under- and over-provision and of both efficient and inefficient use of investment.

The positive effect of infrastructure on growth should not lead to the conclusion that additional infrastructure spending will always be optimal. Although infrastructure yields benefits it also entails large costs. Based on an opportunity-cost argument, Barro (1990) showed in an endogenous growth model that additional public infrastructure investment may reduce growth by diverting resources away from other more productive investments. Also, there can be a trade-off between investment in new infrastructure and maintenance spending (Hulten, 1996). If the existing infrastructure stock is not well maintained, additional infrastructure investment will divert resources away from maintenance and operation spending and impinge negatively on growth.

2.2. Benchmarking infrastructure performance by cost-benefit analysis of new projects

2.2.1. Cost-benefit analysis

Cost-benefit analysis (CBA) aims at measuring the impact of new infrastructure projects on welfare. In theory, all desirable and undesirable outcomes of infrastructure services on all affected parties need to be considered and monetised over the whole life of an infrastructure project. Externalities, for which no market prices exist, are monetised by means of shadow prices. After discounting, the social rate of return of infrastructure projects, which provides a gauge of whether or not they are socially worthwhile, can be estimated and compared across projects and countries (Box 1).

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3.   The literature on the effect of infrastructure on growth is vast. The pioneering studies by Aschauer (1989*a* and 1989*b*) for the United States reported a large impact of the public capital stock on growth, also suggesting the existence of substantial externalities. More recent research found lower, but still positive, effects on growth. Agénor and Moreno-Dodson (2006) provide a literature review.

Box 1. **Cost-benefit analysis: main aspects and a concrete example**

CBAs are complex exercises involving market and non-market valuations. Countries have developed guidelines on how to conduct CBAs so as to guide the government in its investment decisions. Persson and Song (2010) review the planning and CBA practices in the transport sector of seven OECD countries (Australia, France, Korea, the Netherlands, Norway, Sweden and the United Kingdom). A few countries also carry out CBAs *ex-post*. France is one of them (see below). Although CBA methodologies differ across countries, they share common aspects:

- A large set of benefits and costs generated by infrastructure projects are scrutinised. As compared with a financial cost-benefit exercise, whose aim is to measure the profitability of a project, more components are taken into account (for instance, consumer surplus and the externalities a project generates);

- A long planning horizon (20, 30 or more years) is often needed as many infrastructure assets have a long life;

- To calculate the net present value of a project, future benefits and costs are discounted. Some argue that the discount rate should be based on a long-term market interest rate as it reflects people's inter-temporal preferences; others favour a lower discount factor to place more weight on future generations; some adjust the discount rate for risks associated with the project or for the opportunity costs of using public funds;

- All costs and benefits need to be converted into monetary values. Those costs and benefits with no market valuations are evaluated through shadow prices derived by different techniques. These include observed behaviour in other markets, questionnaires to infer willingness to pay, hedonic pricing methods (*e.g.* to estimate the impact of pollution on house prices) and insurance markets (*e.g.* insurance payments in the case of an accident);

- Sensitivity analyses are usually conducted to verify the robustness of the results. These can involve the use of alternative discount factors, adding omitted costs and benefits whose valuation is uncertain or using alternative demand forecasts.

Distributional issues are usually not addressed in CBAs. If a project makes some individuals better and others worse off and the gains exceed the losses, the project will still improve social welfare. In principle, while winners could compensate the losers so as to generate a Pareto improvement, this does not need and does usually not take place. Distributional weights could theoretically overcome this problem, but there are no widely accepted methods to assign these weights and consequently they are not used often.

A concrete example of a CBA: the high-speed train line between Paris, Orléans, Clermont-Ferrand and Lyon

This high-speed train line is at the planning stage and if the project goes ahead, it should be operational in 2025. The rail track company, Réseau Ferré de France (RFF) has commissioned a CBA, which was made public (Setec International, 2011) and will serve as a key element in the decision process. For six key groups concerned by the infrastructure project, the CBA recognises changes in welfare, mostly travel time saved for users and increased profits for rail companies, but also externalities such as the reduction in pollution (Table 1). Each benefit and cost is monetised, on the basis of rules common to all infrastructure projects. The calculation of the net present value of the project is based on a discount rate, which declines over time (4% up to 2034, 3.5% from 2035 to 2054 and to 3% from 2055). The main winners of the project are train users, rail companies and road users while the government, road and air operators would face a loss. The internal rate of return is expected to be positive (3.8% if the opportunity cost of public funds[1] is accounted for, or 4.5% otherwise). The CBA report also contains sensitivity tests, with alternative scenarios, including for projected economic growth – and hence the use of new train services – over the period 2009-25, carbon prices, investment costs and the degree of inter-modal changes.

<table>
<tr><td colspan="2" align="center">Table 1. Main elements accounted for in the cost-benefit analysis</td></tr>
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Groups/actors	Main elements accounted for in the CBA
Existing and new railway users	Change in travel time and costs, including: • Travel costs for existing users (increase in the price of train tickets) and for new users (cost differences between road/air and train travel) • Travel time (both for existing and new train users) • Service quality (number of connections and frequency of train services) • Delay and congestion risks for the existing Paris-Lyon high-speed train line
Other citizens	Externalities (monetised based on rules common to all infrastructure project CBAs): • Better road conditions and less road accidents as some of the road users will switch from roads to trains • Reduced road congestion and shorter travel time • Reduced local air pollution and GHG emissions (noise pollution is not accounted for)
Rail track and rail operators	Increase in turnover as well as investment and operating costs
Motorway and airline operators	Loss in turnover and cut in maintenance and operational costs
Government	Change in tax revenues (excise taxes on oil, VAT, income taxes, etc.) resulting from the reduction in road and air traffic and the increase in train traffic

Source: Setec International (2011).

Confronting (*ex-ante*) cost-benefit analysis with outcomes

Since 1982, French law requires that an analysis of social, economic and environmental benefits and costs of large transport infrastructure projects be carried out 3 to 5 years after the project became fully operational – the so-called *bilans LOTI*. The law also requires that actual benefits and costs are compared with those used to justify the project (*i.e. ex-ante* CBAs), including the actual costs of building the new infrastructure, its use and the impact on alternative transport modes. In some cases, variations in costs and benefits are large and the actual rate of return stands much below projections. One key difficulty, however, is to define the reference scenario – *e.g.* how would the train and road traffic have evolved in the absence of the new high-speed line – in particular when the infrastructure becomes operational many years after the *ex-ante* CBA (13 years in the above example).

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1. A 1.3 coefficient is applied on public funds required to finance this project so as to reflect the opportunity cost of raising additional taxes.

The net social benefit of a project can be calculated as follows:

Net socio-economic benefit = change in consumer surplus + revenues for the infrastructure operator – operating costs of infrastructure services + change in welfare because of externalities + effect on government budget

Estimating the change in consumer surplus

Calculating the change in the consumer surplus is a central issue. This element needs to take into account direct monetary (fees and charges) and non-monetary components. Different methodologies exist to compute it. The simplest is the "rule of one half" and involves calculating the rise in consumer surplus

generated by the increment in demand for infrastructure services under the assumption of a linear demand curve. In this case, the increase in surplus is the change in demand, times the difference in prices divided by two. The "logsum" is an alternative approach to compute the consumer surplus (Box 2). It has been developed specifically for the transport sector but applications have thus far been limited.

Box 2. **Calculation of the consumer surplus by means of the "logsum"**

The "rule of one half" has the advantage of being simple, but it has limitations. When consumers face multiple choices (*e.g.* train, bus, car…) the "rule of one half" is of limited usefulness as it cannot take into account the different transport alternatives. The logsum is an accessibility indicator, which measures the utility of households and businesses of being able to undertake certain activities, *i.e.* the net effect of the costs of a movement and the benefits of an activity. The logsum requires estimating consumers' utility function *via* discrete choice models (De Jong *et al.*, 2005; Train, 2003). The change in consumer surplus caused by a new transport project can then be estimated *via* the change in the logsum. The decision makers' choice among different alternative transport modes is modeled by means of a logit probability model. The decision maker is assumed to choose the alternative generating the greatest utility. The logsum provides an estimate of the expected utility of the decision maker and can be retrieved from the estimated choice-probability logit model. Multiplying this term by the marginal utility of income translates utility into a money measure, which yields the consumer surplus. The change in consumer surplus due to a new transport project can then be computed as the difference in the "logsum" estimated with and without the alternative represented by the new project, multiplied by the marginal utility of income.

Although the "logsum" relies on micro-econometric choice models, it can also be applied at the sectoral level. With a transport model covering (most of) a country's transport network, the logsum can be used to obtain a measure of accessibility. Accessibility can be interpreted as a measure of transport quality as it takes into account the transport costs, the door-to-door travel time, the travel time reliability, comfort and all other factors bearing on consumers' choice of the various transport modes.

Estimating the change in the producer surplus

The difference between revenues and operating costs captures the surplus of infrastructure owners and service providers. Revenues include charges and fees users pay for infrastructure services. Operating costs encompass maintenance and administration costs plus capital amortisation. Also the change in the producer surplus of competitors is taken into account.

Taking externalities into account

Welfare effects due to externalities need to be evaluated. These are heterogeneous across sectors. For instance, in the case of transport they include the social costs of air pollution, noise, congestion and accidents as well as social benefits such as the increase in economic activity and opportunities engendered by new infrastructure. For energy, pollution is likely to be a major source of social costs along with other more general environmental impacts such as aesthetic concerns and water usage. Positive society-wide effects deriving from reliable energy sources represent instead positive externalities.

Shadow prices are key for conducting CBAs. They are used to value the externalities of infrastructure.[4] Drèze and Stern (1990) defined the shadow price of a good as equivalent to the change in social welfare caused by a unit increase in the availability of this good. Shadow values thus represent the social value of commodities and services.

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4.   If markets are competitive and there are no externalities, market prices will equal their shadow values (Drèze and Stern, 1990). However, markets are rarely perfectly competitive and completely undistorted. In these cases, market prices will not reflect their social value. In practice, CBAs use market prices when they are available, presumably under the implicit assumption of perfectly competitive and undistorted markets and because the estimation of shadow prices is contentious.

2.2.2. Frameworks for conducting CBAs differ

When conducting CBAs, countries consider similar sources of costs and benefits but there can be notable differences. Persson and Song (2010) provided an overview of the practices used in some OECD countries for cost-benefit analyses in the transport sector. For instance, France, Norway and Sweden include the costs of financing infrastructure projects through taxes, but not the Netherlands, Korea and the United Kingdom (Table 2). Additional cross-country differences concern noise, local air pollution and climate change, which, for instance, the United Kingdom does not consider. Moreover, CBAs do not take into account all benefits. Positive externalities through indirect effects arising from higher productivity and increasing returns to scales due to agglomeration economies are usually not taken into account. These are hard to measure and there is disagreement on the size of such effects.

Table 2. **Monetised elements in cost-benefit analyses for the transport sector for selected countries**

Element	Norway	Netherlands	Korea	Sweden	United Kingdom	France
Passenger transport time saving	√	√	√	√	√	√
Benefits for goods transport	√	√	√	√	√	√
Safety	√	√	√	√	√	√
Noise	√	√	√	√		√
Local air pollution	√	√	√	√		√
Climate change	√	√	√	√		
Indirect socioeconomic effects		√		√	√	√
Construction cost	√	√	√	√	√	√
Costs for maintenance, operation and administration	√	√	√	√	√	√
Cost of tax financing	√			√		√
User charges and revenues	√	√	√	√	√	√
Vehicle operating costs	√	√	√	√	√	√
Adjustment for optimism bias					√	

Source: Persson and Song (2010) and Odgaard *et al*. (2005).

CBAs rely on various parameter values that can have large effects on results. Table 3 shows the discount rate and appraisal period used in CBAs for the transport sector in selected countries. There are good reasons for parameter values to differ. They should vary according to economic conditions and societal preferences. However, it is unclear to what extent cross-country variation in parameter values is attributable to these factors or to alternative methodologies to derive them.[5]

Økland (2008) showed that using Swedish or UK parameter values alters the results of some CBAs conducted in Norway significantly. The Norwegian CBAs showed negative net social benefits. Applying Sweden's parameters they became even more negative whereas using the United Kingdom's yielded positive net benefits. In this context, the discount rate is a crucial parameter. As the time period considered is in general long, reaching 50 years for some projects, and most of the investment takes place upfront, even small variations in the discount rate can have a large impact on net social benefits. For instance, changing the discount rate from 3% to 10% reduces the present value of a benefit ten years into the future by 48% whereas the drop in value of a benefit that is 50 years away is 96%. There is no consensus on what the appropriate discount rate should be.

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5.   In France the discount rate was reduced from 4% in 2005 but it no longer includes risks and the opportunity costs of public funds.

Table 3. **Discount rates and appraisal periods in cost-benefit analyses for the transport sector in selected countries**

	Discount rate	Appraisal period
Austria[1]	2-3%	.
Belgium[1,2]	6.5%	30
Czech Republic[1]	5-7%[6]	20
Denmark[1]	6%[6]	50
Estonia[1]	6%	30
Finland	5%	30
France[4]	4%	.
Germany[1]	3%	.
Hungary[1]	5%	25
Ireland	5%[5]	30
Italy[3]	4-6%[5]	30
Netherlands	4%	Infinite
Poland[1]	6%	20
Portugal	3-6%	20
Slovak Republic[1]	6%	20-30
Slovenia[1]	8%[5]	20-25
Spain[1]	6%	.
Sweden[1]	4%	40-60
Switzerland[1]	2-2.5%	40-infinite
United Kingdom[1]	3.5%	30

Note:
1. Varies by mode/project.
2. Wallonia.
3. Maximum.
4. 4% up to 2034, 3.5% from 2035 to 2054, 3% thereafter.
5. The discount rate includes a risk premium.
Source: Odgaard *et al*. (2005) and Commissariat Général du Plan (2005).

2.2.3. Ex-post evaluations

Ex-post evaluation exercises are useful to assess the actual social return of infrastructure projects. CBAs are prospective exercises and their results depend on numerous assumptions and forecasts, such as traffic flow, number of customers and associated external costs and benefits, which may prove wrong. However, to date only a few OECD countries have introduced *ex-post* evaluations in their planning and evaluation process (Persson and Song, 2010). In France, *ex-post* evaluations are compulsory for projects exceeding EUR 80 million within three to five years of the completion of the project. In the UK, *ex-post* evaluations are conducted for road transport projects in the first and fifth year after completion. At the EU level, *ex-post* evaluations are conducted for large trans-European transport networks. Flyvbjerg (2009) examined more than 200 large infrastructure projects from the 1920s to 1990s and showed that cost overruns, benefit shortfalls and the systematic underestimation of risks are common. For transport, nine out of ten projects had cost overruns and cost estimates do not appear to have improved over time.[6]

Another approach to benchmarking infrastructure sector performance could exploit *ex-post* evaluation data. Ideally, such data would allow for comparisons of the actual social rate of return of infrastructure

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6. For railway projects, cost overruns of 44.7% on average combined with traffic shortfalls of 50% on average. For roads, cost overruns of 20.4% on average were accompanied by a 50% chance that the traffic forecast is wrong by more than 20%.

projects. However, the coverage of *ex-post* evaluations and CBAs is unlikely to be the same across countries. Some countries are likely to conduct them more systematically than others and value thresholds above which public agencies are obliged to perform them differ across countries. These issues risk resulting in non-representative samples.

2.2.4. Issues related to benchmarking infrastructure based on CBAs and ex-post evaluations

- *Parameter values of CBAs and ex-post evaluations.* Benchmarking in the sense of making cross-country comparisons could be hampered if differences in the social rate of return across countries for similar projects are due to dissimilar parameter values. Differences in key parameters may reflect societal preferences or differences in underlying methodologies. Applying the same parameter values to all countries with the intention to make project evaluations more comparable could impose the same value judgments on all of them, which may be inconsistent with countries' actual social and welfare priorities.

- *The role of private investment.* CBAs and *ex-post* evaluations of new infrastructure projects may not cover private investment, which would limit the scope of this approach to benchmarking as it would only address infrastructure sectors where public provision is dominant.

- *Country-specific factors affecting the rate of return.* Country-specific factors, especially geography, may play a substantial role in explaining differences across countries in the rate of return of similar projects. This may bias benchmarking based on cross-country comparisons. For instance, the transmission losses of the electricity grid depend on the length of transmission lines, which in turn are affected by the geography of the country as it determines the location of electricity-generating plants. The same argument applies to the road sector. Mountainous *versus* flat landscapes may affect road quality and performance in addition to construction and maintenance costs.

2.3. Benchmarking infrastructure performance based on the social efficiency of service provision

This approach aims at computing the social productivity or efficiency of infrastructure service provision by relying on a production function approach. Social productivity can be thought of as a traditional productivity/efficiency measure that also takes into account positive and negative externalities.

Approaches to correct productivity or efficiency indices for undesirable outcomes include distance functions and data envelopment analysis (DEA) (Färe *et al.,* 1993; Seiford and Zhu, 2002; Färe and Grosskopf, 2004).[7] These methodologies permit modelling multi-output technologies. No information on prices and shadow values are needed. Output distance functions have also the advantage of making it possible to estimate the shadow values of outputs (Färe *et al.,* 1993).

Externality-adjusted efficiency measures have been estimated for some infrastructure sectors using micro or industry level data. Yaisawarng and Klein (1994) used DEA to estimate the productivity of United States' electricity generating plants in the 1980s considering electricity generation as a desirable output and sulphur emission as an undesirable one. Social efficiency measures have also been applied to the transport sector, mainly using micro data. Yu (2004) applied DEA to 14 Taiwanese airports considering noise as an undesirable outcome. He found that noise levels lower the efficiency level of some airports

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7. The output distance function measures how close the observed level of output is to the maximum level that can obtained using a given level of inputs. It shows how close a particular output vector is to the production frontier given a particular input vector. By the same token, the input distance function measures how close the observed level of inputs is to the minimum level that could be used to produce a given level of output.

significantly, affecting the final efficiency ranking. Pathomsiri *et al.* (2008) included delays as undesirable outcomes of more than 50 US airports using DEA. Their analyses showed that without considering delays many of the largest and most congested airports were close to the efficiency frontier, but if delays are taken into account many small and less congested airports moved close to the frontier. Chin and Low (2010) compared atmospheric and water pollution-adjusted efficiency levels of Asian ports. Ha *et al.* (2011) estimated and compared the social efficiency of the domestic rail and air transport sectors in Japan including their life-cycle CO_2 emissions as undesirable outcomes in DEA.[8] Their results suggest that aviation is more socially efficient than rail transport. For a given level of inputs, air transport more than compensates higher CO_2 emissions with more desirable outputs in terms of passenger or cargo movements and shorter travel time.

In the same spirit, the Solow productivity residual can be adjusted for undesirable outcomes. It can be calculated as the difference between the weighted average of the growth rates of the different outputs (with weights equal to their share in the total value of output including externalities) and the weighted average of the growth rate of inputs (with weights equal to their cost shares). Considering one desirable (*D*) and one undesirable (*U*) output entering the welfare function $W = W(D,U)$ – with *D* and *U* affecting welfare positively and negatively, respectively – and the infrastructure service production function $W = A\, F(X)$, where *X* is an input vector and *A* the externality corrected productivity level, the growth rate of *A* ($\dot{A}$) can be written as:

$$\dot{A} = \underbrace{s_D \dot{D} + s_U \dot{U}}_{\dot{W}} - \sum s_i \dot{X}_i$$

where $\dot{D}$ and $\dot{U}$ are the growth rates of the desirable and undesirable outputs, s_D, s_U and s_i are the shares in the total value of output of *D*, *U* and factor *i*, evaluated using shadow values (Nanere *et al.*, 2007).

Social productivity measures do not provide measures of the optimal level of infrastructure.[9] To assess whether infrastructure service provision is close to its optimal level one needs to compare marginal social costs with marginal social benefits. In principle, the socially optimal level of infrastructure can be derived from standard profit maximisation methods involving multi-output production functions encompassing all desirable and undesirable outputs along with inputs (Førsund, 2009).[10] First-order maximisation procedures yield the welfare maximising level of the desirable and undesirable outputs for a given level of inputs. The calculation of the socially optimal level of infrastructure under current policy, which may not be optimal, requires a complete set of quantity and price (or shadow value) data for the different inputs and outputs, which would be very ambitious in terms of data requirements. This approach would focus on current benefits and costs only without considering future ones.

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8. Life-cycle CO_2 emissions include emissions from both the construction and operation of the infrastructure network.

9. For instance, the calculation of the Solow residual assumes that inputs are at their optimal level. This makes it possible to weight their growth rates with their cost shares.

10. Førsund (2009) provides an overview of the different strategies to model multi-output production functions with desirable and undesirable outputs. Different assumptions can be made concerning the substitutability and complementarity between them. These generally involve coupling or weak disposability, meaning that given a certain production technology undesirable outputs can be reduced only by decreasing also desirable outputs. This contrasts with the assumption of free disposability, whereby an increase in one output can be achieved only at the expense of at least another output.

2.3.1. Issues related to benchmarking infrastructure based on the social efficiency of service provision

- *Outcomes versus outputs.* Benchmarking the effectiveness and efficiency of infrastructure across countries raises a number of measurement issues. These problems have also been confronted in OECD studies on the efficiency of public spending on education and health care (Häkkinen and Joumard, 2007 and Sutherland *et al.,* 2007). In both cases, a focus on outcomes, not on outputs, was chosen, as this is clearly conceptually better.[11] Defining the key infrastructure outcomes is, however, difficult. Taking transport infrastructure as an example, connectivity (*i.e.* securing that people and goods can travel in a timely manner to where they want) is often considered as a key outcome. But this concept is vague and partial (*e.g.* it excludes quality aspects and predictability of the journey for transport). Data on outputs, such as total passenger and freight traffic are, however, available.

- *Performance of the infrastructure sector versus the infrastructure grid.* A choice needs to be made whether to measure the performance of an entire infrastructure sector or the grid only. For instance, the electricity sector encompasses generation, transmission and distribution. The performance of the electricity transmission and distribution grid could, in principle, be assessed separately from that of electricity generation. A similar argument applies to railways where the management, operation and performance of the actual railway network can be distinguished from that of the rolling stock (*i.e.* train companies). In practice, however, for certain sectors it may be difficult to isolate the outcomes of the infrastructure *per se*. For instance, the speed and predictability of a train journey depend on the quality of tracks, the signaling system and the rolling stock.

- *The level of aggregation.* Broad infrastructure sectors, *i.e.* energy, transport, telecommunications and water and sanitation, can be sub-divided into more disaggregated sub-sectors, such as road, railway, air and sea transport for transport, gas and electricity for energy, fixed line, mobile and internet services for telecommunications. Benchmarking could start by considering these disaggregated sub-sectors. Such an approach would, however, pose the challenge of how to aggregate the disaggregated performance measures to attain an overall transport or energy infrastructure performance indicator. The sub-sectors' weights in an aggregate index should reflect the importance of the disaggregated sub-sectors, which may not be easy to establish. Ideally, aggregate performance measures should take into account sub-sector interactions. For instance, intermodal technologies affect the efficiency of the transport sector as a whole.[12] Also, the type of electricity generation determines the pollution generated by electric rail transport.

- *Country-specific factors.* As for the project-level CBA evaluation approach, country-specific factors may affect cross-country comparisons of infrastructure performance. For instance, population size, population density, size of the country, size of forest area and others may need to taken into account when assessing the performance of the electricity or road network.

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11. For the primary and lower secondary education sector, PISA scores were identified as the best outcome measure, as opposed to output measures such as the number of teaching hours or the number of pupils educated. Likewise for the health care sector, it was decided to focus on the population health status, instead of outputs such as the number of health care treatments.

12. Inter-modality refers to services and technologies facilitating the transfer of people and cargo from one mode of transport to another.

3. Countries' experience with infrastructure benchmarking

Australia, Canada, New Zealand, the United Kingdom and United States have conducted national or cross-country infrastructure benchmarking. These benchmarking exercises all rely on a set of disparate indicators, and thus fail to provide an overall performance measure of the infrastructure sector. Table 4 summarises the nature, scope and results of these exercises. Overall, they are quite diverse in their approach depending on their objectives and data availability. Some of them, such as the one covering the transport sector of the Canadian provinces, reached the conclusion that even data within the same country were too heterogeneous to be comparable. The US exercise concluded that the dearth of data is the main hurdle for the creation of comprehensive performance measures. Australia and New Zealand share an ongoing benchmarking exercise for the road sector based on very detailed indicators being regularly collected, updated and reviewed. Australia also conducted a benchmarking exercise in the 1990s covering infrastructure service operators in different sectors and countries. Data were collected with a specifically designed questionnaire and from companies' accounts.

The UK's benchmarking exercise is one example of a country relying on a large set of hard indicators (HM Treasury, 2011). For major roads, the performance index includes six dimensions: capacity, access and availability (motorway density); asset or capacity utilisation (average capacity utilisation of motorways); service quality (average vehicle delay on the slowest 10% of journeys); asset condition; carbon emissions; and safety (fatalities). The indicators are indexed at 100 in 2005 and then aggregated to the major roads performance index using equal weights. Figure 1 shows that the overall performance index has improved considerably since 2005, driven by the rapid decline in fatalities, while the other indicators hardly change. The overall performance index is then compared with a cost index, captured by investment and maintenance spending on major roads.

Figure 1. **Major roads performance and cost in the United Kingdom**
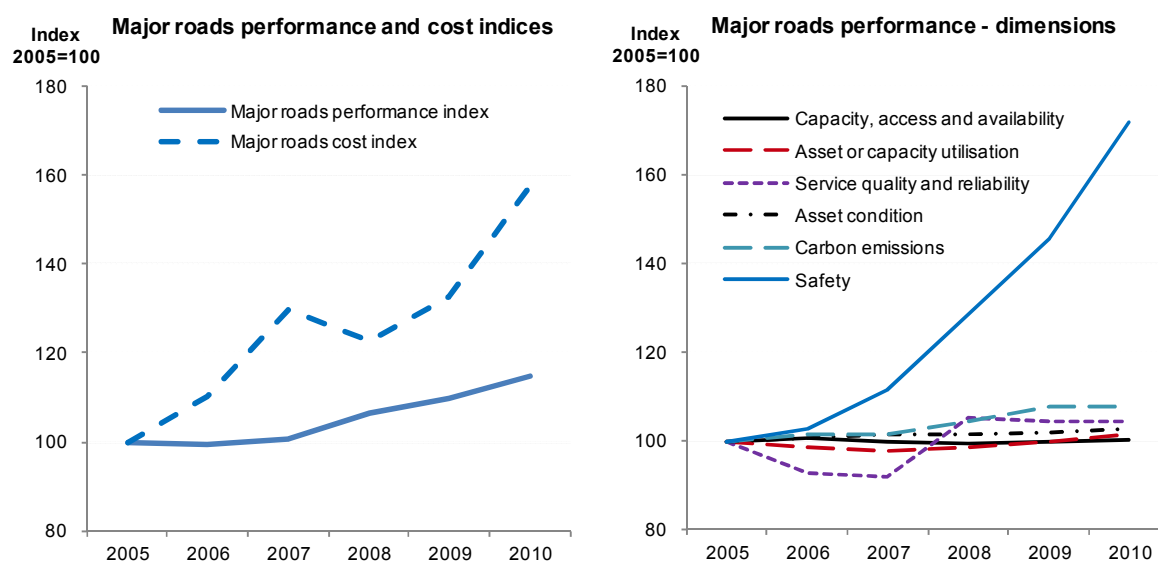
Source: HM Treasury (2011), *National Infrastructure Plan 2011*.

Table 4. **Countries' experience with the benchmarking of infrastructure performance**

	Australia	Australia and New Zealand	Canada	United Kingdom	United States
Aim and context	Understanding how the Australian infrastructure service providers compare with selected service operators in developed and developing countries. Data covered Australia plus other countries	To develop and implement a set of comparable performance indicators for the road sector covering its economic, social and environmental impacts. Data cover Australia and New Zealand.	Understanding how different provinces and territories in Canada collect and utilise infrastructure output indicators. Data covered Canadian provinces and territories (national benchmarking exercise).	Assessing the UK's infrastructure output performance and costs over time and against other countries relying on hard data instead of perceptions, such as the World Economic Forum ranking; included in the *National Infrastructure Plan 2011*. Data on the UK and other OECD countries (international benchmarking) are provided.	To propose a framework to improve measurement of infrastructure performance and propose feasible and comparable performance measures. Data on the USA (national benchmarking)
Period	1991-96	1993-to present	2006	2005-10	In the mid-1990s
Sectors	Electricity, rail freight, telecommunications, waterfront, road freight, coastal shipping, aviation, gas	Road transport	Road transport	Roads, rail, airports, ports, electricity, gas, telecommunications, water and sewerage, flood management, waste	Transport, water and wastewater, municipal waste
Output areas	Price, service quality, labour productivity, capital productivity	Safety, asset management, travel speed and congestion indicators, lane occupancy rate, user satisfaction, prices	Safety, transportation system preservation, sustainability and environmental quality, cost effectiveness, reliability, mobility accessibility	Capacity, access and availability, asset or capacity utilisation, service quality and reliability, asset condition, carbon emissions, safety, cost index	Effectiveness (including service delivery and quality of services), reliability, costs
Approach and data collection	Collects quantitative data to build easily understandable indicators for each output area; data collected from Australia's main infrastructure service providers and selected analogous companies in developed and developing countries; specifically designed questionnaires and balance sheet inspection	Collects quantitative data to build performance indicators comparable across jurisdictions and over time; data collected from Australia and New Zealand's road authorities	Analysis of qualitative data to understand if and how provinces were collecting information on output performance measures; data collected from Provinces' Transportation Departments through a specifically designed questionnaire	Comparison of output performance and cost indices across time and countries depending on data availability; use of published and unpublished data	Description of current practices in infrastructure performance and recommending changes to collect data to build comparable indicators on a continuing base; no hard data were used
Externalities considered	Some indicators on electricity burnouts, lost merchandise	Congestion only; no indicator on environmental impacts	Road congestion and environmental damage	Considered for some sectors only; roads: carbon emissions of road vehicles and average vehicle delays; rail: percentage of passengers in excess of capacity; electricity: unplanned minutes lost per customer, carbon intensity of electricity generation; gas: gas supply interruptions, gas distribution leakage; water and sewerage: interruptions of supply, total leakage (percentage of distributional input).	None
Main results	Possible to identify in which sectors and output areas Australia was performing above or below the benchmark.	The available indicators enable to compare the road systems across jurisdictions and over time; the set of performance indicators is evolving over time according to their relevance and easiness of collection.	Indicators that the provinces collect differ markedly, making comparisons across provinces within output areas difficult; environmental quality is the area with the least information.	The performance of the infrastructure system appears to have improved over time. However, in the majority of cases, costs for users have risen at a faster rate than performance.	The lack of suitable data is one of the main obstacles for measuring performance; need to improve data collection to enable long-term performance monitoring.

4. Concluding remarks

This paper has reviewed different approaches to benchmark infrastructure performance. A first approach, already widely applied, relies on macroeconomic data to estimate the effect of the infrastructure capital stock on growth. A second approach assesses the performance of new infrastructure projects rather than the existing stock, using use *ex-ante* cost-benefit analysis (CBA) and *ex-post* project evaluations. A third approach involves a mix of the previous two as it focuses on the existing infrastructure stock and measures its social efficiency *via*, for instance, Data Envelopment Analysis.

Albeit useful for growth accounting, the macroeconometric approach does not provide a broad view of infrastructure performance as it neglects those infrastructure outputs that even if not affecting GDP growth are important determinants of social welfare. Compared with the macroeconometric approach, the approach based on CBAs and ex-post evaluations of new infrastructure projects has the advantage that it takes into account several infrastructure outcomes affecting social welfare. However, this approach focuses on new projects and therefore it is unable to assess the performance of the existing infrastructure stock.

The approach based on the social productivity or efficiency of the existing infrastructure stock combines positive aspects of the other two approaches. It can provide an overall view of infrastructure performance taking into account social outcomes focusing on the aggregate capital stock. However, challenges relating to data requirement and comparability loom large and need be addressed. One drawback of this approach is that it is not forward looking.

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