INTERSTATE ROAD OR INTERSTATE RAIL INFRASTRUCTURE: DOES THE COST STRUCTURE MAKE A DIFFERENCE?

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Abstract

In this paper we analyze the role of the cost structure for the supply (pricing and investment) of transport infrastructure by regional governments. We compare transport systems that have, for a given capacity, the same total infrastructure cost but vary in the proportion of fixed costs and variable capacity costs. Road or bus or air transport systems have typically constant returns to scale and low fixed cost while rail systems have typically a very high proportion of fixed costs. The effect of the structure of the cost function on the equilibrium is derived in 3 different settings: first where the infrastructure serves only one isolated region, second where the infrastructure is build and operated by a region that faces a lot of transit and finally where the infrastructure is part of an interstate corridor where the 2 regions building and operating face important transit flows. We show that in many circumstances an infrastructure that has ceteris paribus a higher share of fixed costs generates more welfare for the region building and pricing it and is therefore more easily build. The theoretical results are illustrated numerically with a 2 stage Nash investment – pricing game for a corridor with 2 regions.

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0. Introduction

The structure of the cost function for capacity extension has been at the forefront of discussions by transport economists. Both in academic and policy circles it is often argued that funding of capacity is more problematic when there are high fixed costs of capacity expansion and that, in the absence of federal support, capacity will not, or insufficiently, be provided. The literature has shown (see Mohrung and Harwitz (1962), Small (1982), Arnott and Kraus (1998)) that if the user cost function is homogeneous of degree zero in volume and capacity, capacity is perfectly divisible and the capacity cost function is characterized by constant returns to scale, then optimal pricing (at marginal social cost) implies exact cost recovery. However, with non-constant returns to scale in capacity provision the cost recovery ratio equals the elasticity of the capacity cost function with respect to capacity so that, for infrastructure involving high fixed costs, deficits result. Funding of capacity investments seems quite problematic, therefore, for infrastructure with high fixed costs. Subsidies are needed to implement marginal cost pricing.

Note, however, that in a country where the infrastructure is exclusively used by local demand so that the benefits of investment in infrastructure fully accrue to local users, the impact of economies of scale in capacity provision does not necessarily strongly reduce investment incentives. As long as a government can rely on public revenue that is not too costly and the deficit is not too large, high fixed costs in capacity provision may not prevent implementation of the ideal investment and pricing combination, whatever the structure of the cost function. However, there are at least two reasons why things become different when we use a more realistic setting where regional (country) governments decide on infrastructure, but where part of the users come from other regions or countries.

The first problem is that the regional governments typically care about welfare of local users, but not about the costs of foreign users; only the net revenue contribution they bring in matters. If marginal social cost pricing is used, one expects that the regional government will have a smaller incentive to invest when economies of scale are important and when the share of transit users is high. Through traffic creates congestion and necessitates higher capacity, the cost of which can not be fully

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1 Although, as shown in Morrisson (1983), Zhang and Zhang (2003), dePalma and Lindsey (2005), these results have to be further amended when the congestion function is nonlinear in the volume capacity ratio, the overall message remains broadly the same.
recovered. This has been one of the principle motivations in the EU and the US to subsidize interstate transport investments and to subsidize more heavily the high fixed cost investments (typically mostly rail or canals). These problems are expected to be more acute when the use of the infrastructure can not be tolled.

A second complication is that, of course, in real world transport corridors regional governments are not interested in marginal cost pricing when there is through traffic. In the absence of regulation, regions will charge prices above the marginal social cost as this allows them to generate a profit margin on through traffic (Arnott and Grieson (1981), Levinson (2001), De Borger, Dunkerley and Proost (2006)). When infrastructure can be priced by the regional governments it is no longer clear whether a higher share of fixed costs is a hurdle for efficient investments and whether more or less federal subsidies are called for when there is a higher share of fixed costs.

The purpose of this paper is, therefore, to study the effect of the cost structure of capacity expansion (i.e., the relative share of fixed costs) for regional capacity decisions and for regional welfare. How does the cost structure affect the economics of transport infrastructure projects undertaken by regional governments? Does it reduce the probability that interesting projects are undertaken? If subsidies by federal governments are needed to induce regional governments to take on the projects, do we need more subsidies when the share of fixed costs increases? The analysis is motivated, among others, by recent policies of the European Union (EU). In the EU, member countries can apply for federal grants for their transborder infrastructure projects within the framework of the so-called Trans European Networks (TEN’s). Subsidies seem to be implicitly justified on the basis of the very high shares of transit traffic on European networks. Since the benefits of investment projects are partially flowing abroad, without subsidies it is feared that insufficient incentives would exist for the realization of beneficial projects. In practice, however, subsidy programs are much better developed for rail projects than for road investments, and subsidy levels for rail exceed those for road. The implicit justification for this practice seems to be that rail investment is characterized by very high fixed costs, making cost recovery difficult; assuming marginal cost pricing of infrastructure use, the deficit to be expected is a rising function of the share of fixed costs.

The question is whether these higher investments for rail are always justified from an efficiency viewpoint. In other words, which criteria, in terms of the cost
structure and the importance of transit, should the EU use to allocate subsidies? We analyze the role of the cost structure (presence of high fixed costs) for investment decisions, for cost recovery and for welfare in 3 different settings: first where the infrastructure serves only one isolated region, second where the infrastructure is build and operated by a region that faces a lot of transit and finally where the infrastructure is part of an interstate corridor where the 2 regions building and operating face important transit flows (see De Borger, B., Dunkerley, F. and S. Proost (2006)). The theoretical results are illustrated numerically with a 2 stage Nash investment – pricing game. Four different pricing regimes are considered: no tolling at all, differentiated tolls between local and transit demand, uniform tolls, and tolls on local demand only.

We obtain some interesting results. We show that in many circumstances an infrastructure that has ceteris paribus a higher share of fixed costs generates more welfare for the regional government building it and is therefore more easily build and requires less, rather than more, subsidies. Moreover, we find that, even for capacity characterized by very high shares of fixed costs, financing of infrastructure is generally not an important issue as long as regions are allowed to toll transit traffic. This holds true both in the case of differentiated and uniform tolls. Therefore, the results suggest that the EU should not subsidize the provision of infrastructure if tolling can be decided by the member states. If member states cannot toll transit, or if the EU can impose socially optimal pricing on the transport corridor, then subsidies are justified. In the latter case, subsidies should be a rising function of the share of fixed costs and the importance of transit.

The paper is structured as follows. Section 1 discusses the model set up. Section 2 discusses the case of one isolated region with and without through traffic. Section 3 analyses the case of a transport corridor that runs through 2 countries. Section 4 illustrates with a numerical example the importance of the cost structure for the corridor case. A final section concludes.

1. Model formulation

We opt for the simplest possible formulation: we use linear demand functions, a linear congestion function and linear capacity cost functions. The 3 cases considered are illustrated in Figure 1. In the first case there is only one region (A) that decides on the capacity and pricing of a transport link that is used by local traffic only. In the
second case, the region faces also through traffic. In the third case we consider a corridor where a transport link is controlled by two adjacent regions (A and B) that each control the capacity and pricing on their part of the link. Each part of the link is used by local traffic and by through traffic.

Figure 1 The 3 archetypes studied

We will formulate the model first in its most general form (case 3) but will then study first the simpler cases 1 and 2.

1.1. Demand, prices and user cost specification

Demand for local transport in regions A and B is represented by the strictly downward sloping and twice differentiable inverse demand functions $P_A(Y_A)$ and $P_B(Y_B)$, respectively, where $Y_A$ and $Y_B$ are the local flows on both links. Note that the prices $P_i(.)$ are generalised prices including resource costs, time costs and tax payments or user charges. Overall demand for transit traffic is described analogously by the strictly downward sloping inverse demand function $P^T(X)$, where $X$ is the transit traffic flow that passes through both regions A and B. We distinguish 4 possible pricing regimes, see the following table:
Table 1 The 4 possible pricing regimes

<table>
<thead>
<tr>
<th></th>
<th>Toll on local traffic in region A (and similarly in B)</th>
<th>Toll on transit traffic in region A (and similarly in B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differentiated toll</td>
<td>$t_A$</td>
<td>$\tau_A$</td>
</tr>
<tr>
<td>Uniform toll</td>
<td>$\theta_A$</td>
<td>$\theta_A$</td>
</tr>
<tr>
<td>Toll on locals only</td>
<td>$t_A$</td>
<td></td>
</tr>
<tr>
<td>No toll</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The generalised user cost for transit, denoted as $g^X$, equals the sum of the time and resource costs of travel plus the transit tolls in both $A$ and $B$:

$$g^X = C_A(V_A R_A) + \tau_A + C_B(V_B R_B) + \tau_B$$

with $V_i = X_i + Y_i$

In this expression, the $C_i(.)$ are the time plus resource costs on link $i$, and $R_i$ is the inverse of capacity. The user cost function is twice differentiable and strictly increasing in $V_i R_i$, the total traffic volume relative to capacity. The transit tolls are denoted $\tau_i$. Similarly, the generalised user cost functions for local use of links $A$ and $B$ are given by, respectively:

$$g^Y_A = C_A(V_A R_A) + t_A$$

$$g^Y_B = C_B(V_B R_B) + t_B$$

The $t_i$ are the tolls on local transport.

In the absence of corner solutions, transport equilibrium for transit and local traffic implies

$$P^X(X) = g^X = C_A(V_A R_A) + \tau_A + C_B(V_B R_B) + \tau_B$$

$$P^Y_A(Y_A) = g^Y_A = C_A(V_A R_A) + t_A$$

$$P^Y_B(Y_B) = g^Y_B = C_B(V_B R_B) + t_B$$
We use linear demand and user cost specifications. We prefer the linear demand function because we want a choke price above which demand drops to zero\(^2\). A linear user cost function is used as this is more analytically tractable and can be justified in a bottleneck type of model (Arnott, de Palma, Lindsey, 1993). Specifically, we use as demand and cost functions for country A (and similarly for B):

\[
P^A_d = c_A - d_A Y_A \\
P^X = a - bX \\
C_A = \alpha_A + \beta_A R_A V_A
\]

1.2. Capacity costs and isocost and isocapacity locus

To model the costs of capacity, different formulations are possible. Taking \(Z_i(= \frac{1}{R_i})\), \(i = A, B\) as the measure of capacity in region \(i\), two simple formulations to introduce returns to scale are a linear capacity cost function and an iso-elastic function. The linear cost function has the following structure (where \(C(Z)\) represents the total capacity cost):

\[
C(K) = F + kZ
\]

where \(F\) is a fixed cost \((F=0\) if no capacity is chosen), and \(k\) is a constant cost of capacity expansion. The isoelastic cost function has a structure:

\[
C(Z) = kZ^e
\]

where \(e \leq 1\). Varying \(e\) allows studying the effects of a fixed cost only \((e=0)\) as well as the constant returns to scale case \((e=1)\). In what follows we use the linear specification. The degree of returns to scale can be varied by increasing, for a given \(C(Z)\), the share of \(F\).

In this paper we will study the effect of alternative structures of the capacity cost functions and we will do this along an isocost and isocapacity locus. This is the set of linear capacity cost functions \([C(K) = F + kZ]\) that have the same total cost for a given level of capacity \(Z\). The concept is illustrated in Figure 2. Starting from a reference level of capacity \(Z^0\) and a total cost level \(TC^0\), we can define all combinations of \(k\) and \(F\) that generate the total cost \(TC^0\). We show two combinations on Figure 2: one with no fixed costs and one with important fixed costs. All the

\(^2\) The alternative is a constant elasticity demand function but this implies an infinite willingness to pay for very low quantities so that the transport service is always provided.
combinations are given by the linear function that starts at the Y axis with no fixed costs and ends up at the X axis with no variable costs. In the latter case, of course, the notion of capacity and congestion looses its standard meaning and we will not consider this extreme case.

![Figure 2 Isocost and isocapacity locus](image)

\[ TC^o = 0 + k_1 Z^o \]

\[ TC^o = F_2 + k_2 Z^o \]

**1.3. Objective function of the government**

We assume that the objective function of the local government captures local user benefits, net of user costs, toll revenues and capacity costs. For example, if differentiated tolls can be used, welfare in country A is given by:

\[ W_A = \int_0^{\gamma_A} P^\gamma_A(y) dy - g^{\gamma}_A Y_A + t_A Y_A + \tau_A X - F_A - k_A Z_A \]

The uniform pricing case has \( \theta_A = t_A = \tau_A \), local tolls only imply \( \tau_A = 0 \), zero tolls imply \( t_A = \tau_A = 0 \). This assumption is consistent with a political system where the local users determine the pricing and investment policy in their own region and are not controlled by a federal authority that will care also for the net user benefits of the
through traffic. A federal government will therefore judge policies differently on the basis of the following objective function that includes all user benefits and all costs:

\[
W = \int P_A^Y (y) dy - s_A Y_A + t_A Y_A + \int P_B^Y (y) dy - s_B Y_B + t_B Y_B \\
+ \int P^X (x) dx - g^X X + (\tau_A + \tau_B) X - F_A - k_A Z_A - F_B - k_B Z_B
\]

2. The effect of the capacity cost structure in the case of one isolated country

Take first an isolated region where the infrastructure can only be used by local users. We furthermore assume that for the benchmark cost structure (no fixed costs), it is optimal for the local government to provide the transport infrastructure. Then we consider the effect of altering the cost structure for two different cases: first, we assume there is no transit, next we introduce transit. In both cases, as will become clear below, we can show that when we alter the structure of the cost function along the isocost–isocapacity locus, regional welfare increases.

2.1. The case of a single country with only local demand

Suppose an isolated country only has local transport. It decides on investment and transport tax levels by maximizing regional welfare, as given above. Now start from the case with zero fixed infrastructure costs, and then decrease the variable cost (hence raise the fixed cost above zero) along the isocost-isocapacity line. It then easily follows that welfare cannot decrease, and will in fact rise. The intuition behind this result is simple. Note that the same level of capacity as the one selected in the benchmark solution (without fixed costs) is still feasible. In this case, the cost structure has changed but the total cost and the regional welfare are identical to the benchmark. However, the marginal cost of a unit of additional capacity has decreased. This implies it becomes interesting to add capacity and have reductions in travel costs. This gives us proposition 1, which is formally shown in Appendix 1.
PROPOSITION 1

Assume linear demand, user cost and capacity cost functions, and consider a regional government that maximizes regional welfare and faces only local transport demand. Comparing cost structures along an isocost and isocapacity line then imply that a higher share of fixed costs can only increase welfare.

Large fixed costs, in the sense described above, are therefore beneficial to a welfare maximizing country. However, although welfare rises, marginal cost pricing does imply that a higher share of fixed costs is likely to decrease the cost recovery ratio (equal to variable capacity costs over total capacity costs). To see this, define the cost recovery ratio in a given country, say country A, as

\[ \rho = \frac{t_A^* Y_A}{F_A + k_A Z_A} \]

One easily shows that the optimal toll and capacity rules that result from welfare maximizing behavior are given by, respectively:

\[ t_A = \beta_A Y_A R_A \]

\[ \beta_A Y_A^2 = \frac{k_A}{R_A^2} \]

where the right hand side of the toll rule is precisely the marginal external cost. Noting that \( R_A = \frac{1}{Z_A} \) and substituting immediately yields:

\[ \rho = \frac{k_A Z_A}{F_A + k_A Z_A} \]

The cost recovery ratio is the share of variable costs in total capacity costs, a simple application of the general rules derived by Mohrung and Harwitz (1962): the cost recovery ratio equals the elasticity of capacity cost with respect to capacity. Although changes in the cost structure obviously affect optimal capacity \( Z_A \), this does suggest that, the higher the importance of fixed costs, the lower the cost recovery ratio, given optimal pricing\(^3\). This is probably the basis for financing concern in policy circles with respect to infrastructure investment involving high fixed costs.

\(^3\) Taking into account the impact of the cost structure on capacity, one easily shows that the effect of higher fixed costs along an isocost-isocapacity line on the cost recovery ratio is highly plausibly negative.
The above implies that if the transport system is run privately, it will require a higher subsidy when fixed costs are more important. This implies a dilemma: systems with high fixed costs are welfare-improving but also raise the deficit. However, as long as only local users make use of the infrastructure and the regional government has access to public funds whose marginal cost is not too far above 1, a lower cost recovery ratio is not inconsistent with higher regional welfare. The main idea is simple but has been overlooked somewhat in the literature.

2.2. The case of a single country with local and transit demand

In many federal states, a local infrastructure is also used by non residents. In this case, the regional government has an interest in tax exporting by raising the user charge above the marginal cost (see Arnott and Grieson, 1981). The phenomenon has been confirmed in a transport setting (see, e.g., De Borger et al., 2004, 2005, 2006). However, following the same argument as before, one can again show that a higher share of fixed costs can only improve welfare. Indeed, as the regional government has full control of the pricing and investment decisions, it can always return to the policy that was optimal in the case with lower fixed costs and therefore produce at least the same regional welfare as before. The decrease in marginal capacity cost makes extra capacity beneficial and this raises welfare. This gives proposition 2a.

PROPOSITION 2a.

Assume linear demand, user cost and capacity cost functions, and consider a regional government that maximizes regional welfare but faces both local and transit transport demand. Comparing cost structures along an isocost and isocapacity line then imply that a higher share of fixed costs can only increase welfare.

The proof is given in Appendix 2. Note that Proposition 2 holds whatever the pricing options defined in Table 1. However, it is clear that welfare will be higher the more pricing instruments the regional government can use, as this will allow the region to earn higher margins on through traffic. Interestingly, the proposition also holds when no user charge can be implemented and notwithstanding the fact that transit traffic is decreasing the welfare of the local users. The main explanation for the positive
welfare effect is again that the lower capacity cost allows increasing more easily the capacity level and this also benefits local users.

It is still the case that the cost recovery ratio will probably decline when the share of fixed costs rises. Of course, this need not necessarily pose serious problems. One easily shows (see Appendix 3) that, depending on the pricing instruments available, tax exporting behavior may imply that cost recovery is no problem. If no tax exporting is possible or if the country is limited to marginal cost pricing then, of course, tax revenues are insufficient to cover investment expenses.

The suggestion that a cost structure with high fixed costs is a good thing for the country’s welfare has still another implication, provided one is willing to interpret this finding in a slightly different way. Let us interpret a given combination of \((F,k)\) as a ‘project’, assuming one of many different projects could be executed. Our finding then implies the following Proposition 2b.

**Proposition 2b:** The higher the fixed cost of a project (along an isocost line), the more likely a country is to actually execute a project that is beneficial for all users together, taking account of the welfare of local and transit users.

To show this statement, assume that a region A will only undertake projects for which the welfare contribution, denoted \(W_A\), is positive: 
\[
W_A(t_A, \tau_A, Z_A; k, F) \geq 0
\]
where the policy variables indexed by A stand for the choices made by the regional government. Suppose that the project also benefits foreign users; the surplus of these users is captured by 
\[
W_T(t_A, \tau_A, Z_A; k, F),
\]
assumed to be positive. Note that \(W_T\) stands for the welfare of transit users, which is evaluated at the same values for the policy variables, chosen by country A. As regional governments do not take into account the consumer surplus of these foreign users, this may imply that some projects that are beneficial for the “federation” as a whole (“federally beneficial” projects being defined as projects for which 
\[
W_A(t_A, \tau_A, Z_A; k, F) + W_T(t_A, \tau_A, Z_A; k, F) \geq 0
\]
) are not undertaken by the individual country A. Using proposition 2, it is then straightforward to show that, along an isocost and isocapacity locus, the higher is the level of fixed costs, the higher is the probability that a regional government undertakes a federally beneficial project. This directly follows from the fact that \(W_A\) is an increasing function of the share of fixed costs. The policy implication of this finding is clear,
viz. that that federal support for regional projects becomes less (and not more) necessary when the share of fixed costs rises (compare rail versus road). Indeed, the region is more inclined to execute federally interesting projects the higher the share of fixed costs.

The previous proposition basically looked at different projects where the regions used tolls on its road or rail link. To conclude this subsection, we point out that the above discussion can easily be extended to derive an interesting proposition on the effect of tolling on the willingness of an individual country to execute federally beneficial projects. We limit the attention here to uniform tolls on local and transit demand. Denote by $W_A(\theta_A;F,k)$ the maximum welfare region A achieves for a given cost structure and the optimal toll selected by the region. Similarly, $W_A(\theta_{FB};F,k)$ is the maximum welfare attainable for the given cost structure and first-best optimal tolls at marginal social cost imposed by the federal level. We denote $W_T(\theta_A;F,k)$ and $W_T(\theta_{FB};F,k)$ as the corresponding welfare levels for the transit users. Finally, $W_A(F,k),W_T(F,k)$ are the welfare levels in A and for transit users in the absence of tolling.

Now note the following relations. First, $W_A(\theta_A;F,k)$ and $W_T(\theta_A;F,k)$ are increasing in F along an isocost line. Second, a country cannot be worse off if it has access to tolling compared to the case without tolls, so that

$$W_A(F,k) < W_A(\theta_A;F,k)$$

Third, by definition of first-best pricing it is the case that:

$$W_A(\theta_A;F,k)+W_T(\theta_A;F,k) < W_A(\theta_{FB};F,k)+W_T(\theta_{FB};F,k)$$

Using these relations we easily show the following proposition.

**Proposition 2c:** Allowing uniform tolling implies that more projects that are worthwhile from the federal viewpoint will be regionally implemented. Imposing first-best tolls on regions improves federal welfare, but it decreases the number a projects taken on by an individual region.

The first statement follows because tolling raises regional welfare. Although it also affects total welfare, the first statement immediately follows. The second statement
follows because first-best tolls reduce regional welfare compared to regionally optimal tolls.

2.3. Summary

We can summarize some of the comparative static effects of increasing the share of the fixed costs along the isocost locus, for the 2 cases we have studied above. This is done in the following table:

<table>
<thead>
<tr>
<th>Effect of increased share of fixed costs along isocost line</th>
<th>Case 1 (no through traffic)</th>
<th>Case 2 (with through traffic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional welfare</td>
<td>Increases</td>
<td>Increases (for all 4 pricing regimes)</td>
</tr>
<tr>
<td>Regional+transit welfare</td>
<td>Increases</td>
<td>Increases (for all 4 pricing regimes)</td>
</tr>
<tr>
<td>Optimal capacity</td>
<td>Increases</td>
<td>Increases</td>
</tr>
<tr>
<td>Total capacity costs</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Cost recovery ratio</td>
<td>Probably decreases</td>
<td>Probably decreases</td>
</tr>
<tr>
<td>Probability that a “federally beneficial” project is undertaken</td>
<td>Increases</td>
<td>Increases</td>
</tr>
</tbody>
</table>

Table 2. Comparative statics in the case of one regional government

3. The effect of the capacity cost structure in the case of a serial transport corridor

In this section we extend the argument derived for the simple case of a single country to the case of toll and capacity competition between regions in a serial transport network. We consider two links in a serial transport corridor; each link is operated by a different regional government. Pricing and capacity decisions are the result of a two-stage game between the countries: in the first stage they decide on capacities, at the second stage they make pricing decisions conditional on the investments decided at the first stage. This type of setting was analyzed in De Borger
et al. (2006) for the case of zero fixed capacity costs. The characteristics of the solution were discussed in detail. In this section we are interested in the effect of changing the capacity cost structure for the Nash equilibrium capacity and toll choices. As before, we look at four sets of tolling instruments, see Table 1: no tolls, differentiated tolls, uniform tolls, and local tolls only.

First consider the simplified case without tolling. In Appendix 4, we show the following proposition:

**Proposition 3:**

Assume linear demand, user cost and capacity cost functions, and consider a capacity game between two regional governments that each maximize regional welfare; both regions face local and transit transport demand. Comparing cost structures along an isocost and isocapacity line then imply that the welfare effect of a higher share of fixed costs is theoretically ambiguous. Under plausible conditions, however, it is positive.

The reason for the ambiguity in general is that the cost structure affects welfare in two different ways. First, as in the case of a single country, a higher share of fixed costs in a country raises local welfare, conditional on capacity investment in the other country. Second, however, in a Nash capacity game the cost structure in one country implies strategic responses by the other country. These were obviously absent in the analysis of Section 2. Capacity cost changes in A affect optimal capacity in A and, hence, strategic reactions for optimal capacity in B. Depending on the size of these strategic effects and the slope of capacity reaction functions, this second effect may strengthen or weaken the direct welfare-enhancing effect of higher fixed costs.

Finally, if we consider the impact of cost structure changes in the full capacity-tolling game between the two countries, the theoretical analysis becomes highly intractable. We resort to numerical analysis in the next section to learn more about the role of fixed capacity costs on capacities, tolls and welfare.

**4. Numerical illustration**

In this section we look at the effect of increasing fixed costs and decreasing variable costs on capacity investment, taxes, demand and welfare under different tolling regimes. After briefly discussing calibration of the model, we first consider the situation when there is only local traffic. Both the case with and without tolling is
considered. Then we look at the results of a strategic two-country game in tolls and capacities, where each country faces both local demand as well as transit. We do limit the discussion to the case of symmetric countries.

4.1 Calibration

In order to examine the effect of returns to scale on investment in capacity, we start from the numerical exercise presented in De Borger et al. (2006). In that paper, constant returns to scale were assumed, so that total capacity costs were given by $C(Z) = kZ$. Assuming that the two regions were ex ante symmetric, the numerical exercise was constructed such that, in the no-toll reference equilibrium, local and transit demand each accounted for 50% of total traffic in a given region. The calibrated unit cost of capacity was €18.69. Optimal tolls and investments were then determined for differentiated, uniform and local only tolling regimes.

In all of the exercises reported in this paper, the cost function takes the form $C(Z) = kZ + F$. Starting from $k_0=€18.69$ and $F_0 = 0$, we allow the variable capacity cost to decrease and, simultaneously, the fixed cost to increase in such a way that, for a given $Z^*$, the total cost, $C(Z^*)$, remains constant. The level of $Z^*$ was in each exercise determined as the equilibrium capacity level with constant returns to scale, as determined in De Borger et al (2006). As an example, in the case of the Nash game with uniform tolling, the Nash level of capacity with constant returns to scale (De Borger et al 2006) was $Z^*=1618$, so that $C(Z^*) = 30251$ euros. The values of $Z^*$ for the other cases were determined in an analogous way.

4.2. Effects of the capacity cost structure: The case of a single country without transit

We first look at the effect on the investment decisions of country A when the variable component of capacity cost decreases and the fixed component increases and there is no possibility of transit traffic. The results of varying the share of fixed and variable capacity costs are presented in Tables 3a (tolls are used) and 3b (no tolls), and in Figure 3.

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*4 Calculated from $C(Z)=kZ+F$ with $k=18.7$ and $F=0$. 

Consider Table 3a. The first two lines show the \((k,F)\) pairs. The rest of the table gives, among others, the impact on demand, tolls, capacity levels and welfare. Results are easily interpreted. First note that optimal capacity provision rises when the fixed cost component increases. This is quite intuitive, due to the smaller marginal cost of capacity expansion. Higher capacity further implies lower congestion. Taxes on local traffic, which are equal to local marginal external costs, also reduce markedly due to the large decrease in congestion. The increase in demand is relatively small. As expected, the degree of returns to scale has implications for the relation between toll revenues and total capacity costs \((C(Z))\). The latter have risen because of much higher capacity investments. As expected, toll revenues actually go down when fixed capacity costs become more important, due to substantially lower tolls on just slightly more demand. Cost recovery becomes therefore less favorable.
Table 3a: Single country, effect of changes in the cost structure (tolls, no transit)

<table>
<thead>
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Figure 3: Percentage changes in key parameters as a function of fixed (and variable) capacity costs with no transit traffic

In Table 3b we report the results in the case the country for some reason cannot use tolls and only determines investment optimally. The results are very similar for this no-toll regime.

Table 3b: Single country, effect of changes in the cost structure (no tolls, no transit)
4.3. Effects of the capacity cost structure: Nash competition in tolls and capacities on a serial transport corridor

In this sub-section we look at the role of the capacity cost structure for the resulting Nash equilibria of the toll-capacity game. The results are presented in Tables 4a to 4d and in Figures 4 to 7 below. A number of trends are common to all the results. Decreasing the size of the variable capacity costs raises optimal capacity levels, independent of the tolling regime. Welfare rises in all cases as well. The welfare is in fact positive in all cases but is highest with differentiated tolling, where tax revenue can be extracted from foreign traffic, and lowest with no toll.

In the regimes with differentiated tolling and local tolls only we observe a large decrease in the local toll, as local marginal external costs decrease in line with congestion. The transit toll rises slightly. For the uniform toll regime, the toll marginally declines. To understand this, note that the optimal uniform toll consists of two components (see De Borger et al (2006)), viz., the local marginal external cost and a tax exporting component that depends on the importance of transit and the sensitivity of demand. The second component is numerically most important. The local marginal external cost declines when fixed capacity costs are more prominent, which reduces the toll. The second component, however, increases. This leads to the resulting small decrease in tax in this case.
### Table 4a: Serial corridor with local and transit demand (uniform toll, capacity-toll competition)

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<tr>
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### Table 4b: Serial corridor with local and transit demand (differentiated tolls, capacity-toll competition)

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### Table 4c: Serial corridor with local and transit demand (local toll only, capacity-toll competition)

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**Note:** The tables represent different scenarios for serial corridors with local and transit demand, illustrating the impact of varying tolls and capacity-toll competition on key economic indicators such as tax revenue, cost recovery, and welfare levels.
As in the case without transit traffic, there is also a marked increase in investment in capacity whereas both local and transit demands increase only slightly. Although relative increases in capacity are similar for all pricing regimes, in absolute terms there is greater investment in capacity when no pricing instruments are available or transit cannot be tolled. There is less investment with uniform tolls than with differentiated tolls because further investment would not bring additional revenue from transit traffic as this would also penalise local users.

Considering the cost recovery issue note, unlike in the case without transit, the uniform (Table 4a) and differentiated tolling (Table 4b) cases generate more revenues than required to finance capacity costs. Note, however, that (contrary to expectations), cost recovery is apparently easiest with uniform tolls. Moreover, cost recovery ratios do not monotonically decline when fixed costs become more important (again, contrary to expectations). When only local tolls (Table 4c) can be used, a substantial deficit occurs; it rises in the share of fixed costs, as predicted by the theory. These results show that funding of infrastructure is hardly a problem in tax-capacity games as long as countries are allowed to toll transit. However, it again points at a dilemma: financing of investment is not a problem in this case, but allowing countries to toll transit is not welfare improving (also see below, federal solution).

The welfare effects reported in Tables 3 and 4 can be interpreted also in a slightly different way. They show that in the cases where transit can be tolled (uniform and differentiated tolling cases) the introduction of transit is likely to raise welfare. However, when transit cannot be tolled, we expect welfare to go down if transit is introduced. For example, compare the welfare levels in Table 3a and Tables 4a and 4b. The introduction of transit combined with transit tolls raises welfare. Now compare Table 3a with Tables 4c and 4d. Introducing transit, while not allowing transit to be tolled, reduces welfare.
Figure 4: Percentage changes in key parameters as a function of fixed (and variable) capacity costs with differentiated toll and transit traffic

Figure 5: Percentage changes in key parameters as a function of fixed (and variable) capacity costs with uniform toll and transit traffic
Figure 6: Percentage changes in key parameters as a function of fixed (and variable) capacity costs with local only toll and transit traffic

Figure 7: Percentage changes in key parameters as a function of fixed (and variable) capacity costs with no toll and transit traffic
Finally, in Table 5 we present the ‘federal’ solution to the two region price-capacity problem. This implies uniform tolls equal to the global marginal external cost (taking into account time losses imposed on transit). Again, capacity and welfare is rising in fixed cost; cost recovery declines in fixed cost. Obviously, cost recovery associated with optimal behaviour at the federal level is again problematic when there are fixed infrastructure costs. Together with the results in Table 4, these findings illustrate again the dilemma for federal authorities. Even when there are high fixed costs, toll-capacity competition does not pose serious funding problems as long as transit can be tolled; however, toll-capacity competition is welfare-reducing. To solve funding problems, two options are open. If there are fixed costs, the federal level can impose efficient pricing and investment but then needs support funding, or it can allow regions to toll transit. This implies funding is no problem but results in welfare losses at the federal level.

<table>
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Table 5. The centralised solution

5. Conclusions

TBCompleted.
References


De Borger, B., Dunkerley, F. and S. Proost, 2006, Strategic investment and pricing decisions in a congested transport corridor, discussion paper 06.09, Center for Economic Studies, Katholieke Universiteit Leuven.


Appendix 1: Proof of Proposition 1

Given the isocost/capacity structure $TC - k_A Z_A^* = F_A$, where the total cost $TC = k_A^* Z_A^*$ is taken to be the cost of optimal capacity investment ($Z_A^*$) under constant returns to scale, the fixed costs ($F_A$) can be determined as a function of variable costs ($k_A$)

$$F_A = (k_A^* - k_A) Z_A^*$$  \(1\)

The impact of a higher share of fixed costs on welfare is given by:

$$\frac{dW_A}{dk_A} = \frac{\partial W_A}{\partial k_A} + \frac{dW_A}{dR_A} \frac{\partial R_A^{opt}}{\partial k_A}$$  \(2\)

where $R_A^{opt}$ is optimal inverse capacity. This of course implies the first-order condition $dW_A/dR_A = 0$, so that (2) simplifies to $\frac{dW_A}{dk_A} = \frac{\partial W_A}{\partial k_A}$.

It can be shown that for linear demand and congestion functions, welfare take the form

$$W_A = -Y_A^2 \left[ \frac{d_A}{2} + \beta_A R_A \right] + Y_A \left[ c_A - \alpha_A \right] - F_A - \frac{k_A}{R_A}$$  \(3\)

Substituting from (1) and differentiating, we obtain

$$\frac{\partial W_A}{\partial k_A} = -\frac{1}{R_A} + \frac{1}{R_A^2} = -Z_A^{opt} + Z_A^*$$  \(4\)

It easily follows that $Z_A^{opt} > Z_A^*$, so that the expression is negative. To show this note that, since $Z_A^*$ corresponds to optimal capacity at variable capacity cost $k_A^*$, the inequality $Z_A^{opt} > Z_A^*$ holds provided that $\partial Z_A^{opt}/\partial k_A < 0$ (or $\partial R_A^{opt}/\partial k_A > 0$). Now, the first order condition on capacity, $dW_A/dR_A = 0$, takes the form

$$-Y_A^2 \beta_A + \frac{k_A}{R_A^2} = 0$$  \(5\)

in the case of tolls; for the no toll regime it can be written as

$$-\beta_A Y_A^2 \frac{d_A}{d_A + \beta_A R_A} + \frac{k_A}{R_A^2} = 0$$  \(6\)

where capacities are optimal. Letting $f$ denote the LHS of (5) or (6), the implicit function theorem tells us that

$$\frac{\partial R_A^{opt}}{\partial k_A} = \frac{\frac{\partial f}{\partial k_A}}{\frac{\partial f}{\partial R_A}}$$  \(7\)
Appendix 2: Proof of Proposition 2

As for Proposition 1, we can show that \( \frac{dW_A}{dk_A} = -\frac{\partial R_A^o}{\partial k_A} < 0 \). To do so, note that for all the tolling regimes, the first-order condition on capacity \( dW_A/dR_A = 0 \) takes the form \( f = G(R_A) + \frac{k_A}{R_A^2} \). Here the function \( G(R_A) \) is independent of \( k_A \), since investment costs do not appear in the first-order conditions which determine taxes for given capacity \( dW_A/d\tau_A = 0 \), where \( \tau_A = \tau_A, \theta_A \) nor in the demand and congestion functions. Again, appealing to the implicit function theorem, we can write

\[
\frac{\partial R_A^o}{\partial k_A} = -\frac{\partial f}{\partial k_A} \quad (8)
\]

The denominator of (8) is negative as \( \frac{\partial f}{\partial R_A} = \frac{\partial^2 W_A}{\partial R_A^2} \bigg|_{R_A^*} < 0 \) is the second order condition for optimal capacities. Simple differentiation yields \( \frac{\partial f}{\partial k_A} = \frac{1}{R_A^2} > 0 \) and (8) is therefore positive. Hence the condition that \( \partial Z_A^{op} / \partial k_A < 0 \) is satisfied.

Appendix 3: Cost recovery and pricing instruments

In this appendix we look at the role of pricing instruments for cost recovery in the case a country faces both local demand and transit. First take the case of differentiated tolls. The cost recovery ratio is:

\[
\rho = \frac{t_A Y_A + \tau_A X}{F_A + k_A Z_A}
\]

As shown elsewhere (De Borger et al., 2005, 2006), the optimal toll rules are given by:

\[
t_A = \beta_A R_A (X + Y_A)
\]

\[
\tau_A = \beta_A R_A Y_A - X \eta_A, \quad \eta_A < 0
\]
The optimal capacity rule can be written as:

$$\beta_\alpha Y_\alpha (X + Y_\alpha) - (\tau_\alpha - \beta_\alpha Y_\alpha R_\alpha) \frac{\partial X}{\partial R_\alpha} - (t_\alpha - \beta_\alpha Y_\alpha R_\alpha) \frac{\partial Y_\alpha}{\partial R_\alpha} = \frac{k_\alpha}{R_\alpha^2}$$

Substituting the toll rules in the cost recovery expression and using the capacity rule yields, after simple algebra:

$$\rho = \frac{k_\alpha Z_\alpha - X^2 \eta_\alpha (1 + \varepsilon_Z^Y) + \frac{\beta_\alpha XY_\alpha}{Z_\alpha} (1 - \varepsilon_Z^Y)}{F_\alpha + k_\alpha Z_\alpha}$$

where $$\varepsilon_Z^X = \frac{\partial X}{\partial Z_\alpha} \frac{Z_\alpha}{X}$$, $$\varepsilon_Z^Y = \frac{\partial Y_\alpha}{\partial Z_\alpha} \frac{Z_\alpha}{Y_\alpha}$$ are the demand elasticities of transit and local transport with respect to capacity provision. If there is no transit we have the rule derived before. The effect of the second term in the numerator is to raise the cost recovery ratio. The final term in the numerator raises the ratio even further as long as the elasticity of local demand with respect to capacity provision is less than one. It follows that the cost recovery ratio is higher than in the absence of transit, and can actually easily exceed one. It does decline in the share of fixed costs.

Second, let us look at uniform tolling. The cost recovery ratio is:

$$\rho = \frac{\theta_\alpha (Y_\alpha + X)}{F_\alpha + k_\alpha Z_\alpha}$$

The optimal toll and capacity rules are (De Borger et al. (2006)):

$$\theta_\alpha = \beta_\alpha R_\alpha Y_\alpha - \frac{X}{\frac{\partial Y_\alpha}{\partial \theta_\alpha} + \frac{\partial X}{\partial \theta_\alpha}}$$

$$Y_\alpha \left\{ \beta_\alpha \left[ R_\alpha \left( \frac{\partial Y_\alpha}{\partial R_\alpha} + \frac{\partial X}{\partial R_\alpha} \right) + (X + Y_\alpha) \right] \right\} - \theta_\alpha \left[ \frac{\partial Y_\alpha}{\partial \theta_\alpha} + \frac{\partial X}{\partial \theta_\alpha} \right] = \frac{k_\alpha}{R_\alpha^2}$$

Combining these expressions yields, after simple algebra:

$$\beta_\alpha Y_\alpha (X + Y_\alpha) = -X \left[ \frac{\partial Y_\alpha}{\partial R_\alpha} + \frac{\partial X}{\partial R_\alpha} \right] + \frac{k_\alpha}{R_\alpha^2}$$

Substituting this result into the cost recovery expression leads to, using the definition of $$R_\alpha$$ and some simple manipulations:

$$\rho = \frac{k_\alpha Z_\alpha - X (X + Y_\alpha) (1 - \varepsilon_Z^Y)}{F_\alpha + k_\alpha Z_\alpha}$$

where $$\varepsilon_Z^Y$$ is the elasticity of total transport demand (local plus transit) with respect to capacity increases. In other words:

$$\varepsilon_Z^Y = \frac{\partial V_\alpha}{\partial Z_\alpha} \frac{Z_\alpha}{V_\alpha}$$, \(V_\alpha = X + Y_\alpha\)

It follows that, provided the demand elasticity with respect to capacity is less than one, the cost recovery ratio rises both in total demand and in the importance of transit
demand. Again, it can easily exceed one. If there is no transit, we have the same rule as the one derived before for the case of local tolls only.

Finally, consider the case of local tolls only. We again have that:

$$\rho = \frac{t_A Y_A}{F_A + k_A Z_A}$$

The optimal toll is given by:

$$t_A = \beta_A R_A Y_A s_A$$

where $s_A = 1 + \frac{\partial}{\partial Y_A} Fk Z$, $0 < s_A < 1$ (see De Borger et al. (2005, 2006)). The optimal capacity rule is given by:

$$Y_A \beta_A (X + Y_A) - (t_A - \beta_A R_A Y_A) \frac{\partial Y_A}{\partial R_A} + \frac{\partial X}{\partial R_A} = \frac{k_A}{R_A}$$

Using these expressions we easily show the cost recovery ratio to be equal to:

$$\rho = \frac{s_A k_A Z_A + s_A \left[ (s_A - 1) \frac{\partial Y_A}{\partial R_A} - \frac{\partial X}{\partial R_A} \right] \beta_A R_A^2 Y_A - s_A \beta_A R_A XY_A}{F_A + k_A Z_A}$$

If there is no transit this reduces to the expression derived before. Note that cost recovery may be problematic in this case when there is much transit. Indeed, $s_A < 1$ and, although the second term is positive, the final term in the numerator is negative (and large when transit is important). The reason is that high transit demand induces the country to charge low local tolls, yielding low revenues. The problem is likely to be more severe when the fixed cost component rises.

**Appendix 4: Sketch of Proof of Proposition 3 (to be completed)**

Assume countries impose no tolls, but only compete in capacities. The first order conditions for optimal capacity in each country implicitly define the reaction functions in capacities. Solving these reaction functions, we can then write the Nash equilibrium inverse capacities in general as a function of the cost variable parameters:

$$R_A^{NE} = R_A(k_A, k_B)$$

$$R_B^{NE} = R_B(k_A, k_B)$$

Welfare levels at the Nash equilibrium are obtained by substituting the Nash equilibrium inverse capacities into the respective welfare functions; they can be written in general:

$$W_A^{NE} = W_A \left( R_A^{NE}, R_B^{NE}, k_A \right)$$

$$W_B^{NE} = W_B \left( R_A^{NE}, R_B^{NE}, k_B \right)$$

(9)

To study the effect of an increase in the fixed cost share in $A$ on welfare at the Nash equilibrium for $A$, we totally differentiate to obtain:

$$\frac{dW_A}{dk_A} = \frac{\partial W_A}{\partial k_A} + \frac{\partial W_A}{\partial R_B} \frac{\partial R_B^{NE}}{\partial k_A}$$

(10)
where we have used the fact that optimal capacity in A implies that $\frac{\partial W_A}{\partial R_A} = 0$.

Expression (10) shows that the effect of a change in the cost structure has a direct and an indirect component. The first term on the right hand side is the direct effect. As in the proofs of Propositions 1 and 2, we again have:

$$\frac{\partial W_A}{\partial k_A} = -Z_A + Z_A^* = -\frac{1}{R_A} + \frac{1}{R_A^*}.$$  

This can again be shown to be negative, using exactly the same procedure. So the direct effect of higher fixed cost shares is to raise welfare.

The second component on the right hand side of (10) captures the effect of changes in the cost structure in A on welfare in A via the strategic response of region B. The cost change in A affects optimal capacity in B (because it affects capacity in A and hence transit, which induces B to optimally respond by adjusting capacity); the capacity change in B in turn affects welfare in region A. To study the sign of these effects, let us start with $\frac{\partial W_A}{\partial R_B}$. This is easily shown to be positive: more capacity in B raises transit demand and therefore, reduces welfare in A. Proof is as follows. Note that given our specifications we have

$$W_A = [c_A - \alpha_A]Y_A - \left(\frac{d_A}{2} + \beta_A R_A\right)Y_A^2 - \beta_A R_A Y_A X - F_A - \frac{K_A}{R_A}$$

so that

$$\frac{\partial W_A}{\partial R_B} = [c_A - \alpha_A] \frac{dY_A}{dR_B} - \left(\frac{d_A}{2} + \beta_A R_A\right) 2Y_A \frac{dY_A}{dR_B} - \beta_A R_A \frac{d[Y_A X]}{dR_B}$$

or

$$\frac{\partial W_A}{\partial R_B} = -\beta_A R_A Y_A \left[\frac{dX}{dR_B} + \frac{dY_A}{dR_B}\right] + \frac{dY_A}{dR_B} [c_A - \alpha_A - d_A Y_A - \beta_A R_A V_A]$$

Given the linear demand specification, and using the result (derived in De Borger et al. (2006)) that higher capacity in B raises transit demand, we have:

$$\frac{\partial W_A}{\partial R_B} = -\beta_A R_A Y_A \left(\frac{d_A}{d_A + \beta_A R_A}\right) \frac{dX}{dR_B} > 0$$

Finally, the effect of variable capacity cost in region A on Nash equilibrium inverse capacities in B is ambiguous. However, differentiating system (9) it easily follows that the term $\frac{\partial R_B^{\text{NE}}}{\partial k_A}$ has the same sign as the slope of the reaction function in capacities. This makes sense: if variable capacity cost in A rises along an isocost-isocapacity line (hence fixed cost goes down) capacity in A will decline; this will reduce (raise) capacity in B if reaction functions are upward (downward) sloping. Although the numerical analysis suggests that reaction functions are very plausibly upward sloping this need not generally be the case.

In summary, the first term on the right hand side of (10) is negative, the second term is positive (negative) if capacity reaction functions are upward (downward) sloping. The numerical analysis suggests that the first term dominates, however, so that raising the fixed cost share is welfare improving.