On the supply of network infrastructure

Rietveld, P.; Boonstra, J.

Faculteit der Economische Wetenschappen en Econometrie

Serie Research Memoranda

On the Supply of Network Infrastructure

P. Rietveld
J. Boonstra

Research Memorandum 1993-35

juli 1993

vrije Universiteit *amsterdam*

ON THE SUPPLY OF NETWORK INFRA-STRUCTURE

PIET RIETVELD AND JAAP BOONSTRA[1)]

1. INTRODUCTION

In European countries the supply of network infrastructure such as roads and railway connections nowadays takes place primarily via the public sector. The economic theory on the public sector supply of network infrastructure has a strong normative orientation. This was already present in the work of Dupuit (1844) who made use of the notion of consumer surplus to analyze the benefits of building canals - at that time the most dynamic type of network infrastructure. The consumer surplus concept has become a major element of social cost benefit analysis, a technique used in various European countries to assist public sector decision making in the field of infrastructure. Social cost benefit analysis is essentially a normative instrument. It tells policy makers which investment plans are most attractive and which plans should certainly not be realized.

Public sector decision makers often do not follow the recommendations implied by social cost benefit analysis. There may be good reasons for this, since the focus of social cost benefit analysis is somewhat one sided on the efficiency issue. Equity among groups affected by infrastructure projects is difficult to take into account with social cost-benefit analysis. In addition, there is a general feeling that environmental issues are usually only taken into account rather superficially in cost benefit analysis. In addition to these good reasons, there may be other reasons why actual infrastructure policies are not always based on the normative outcomes of cost benefit analysis. For example, governments used infrastructure investments in the past as an instrument to stimulate the economy via the demand side in the short run without paying attention to the long run benefits. Another example, which was very common in the first part of the 1980's, is that governments solve budgetary problems by decreasing the level of public investments while other types of expenditures (salaries of civil servants, social welfare payments) area kept constant since political pressures to safeguard the latter types of public expenditures are strongest.

The question then arises as to what are the factors explaining public sector decisions on infrastructure. This question can be made more specific by distinguishing decisions on

- the total level of infrastructure investments
- the distribution among infrastructure types
- the spatial distribution of infrastructure investments.

In the present paper we will address the third type of decision. Spatial aspects of infrastructure are discussed in section 2. A model for infrastructure supply is formulated in section 3. In section 4 empirical results are presented. In section 5 a more detailed analysis is given of infrastructure supply in border regions. Concluding remarks are formulated in section 6.

2. THE SPATIAL DISTRIBUTION OF INFRASTRUCTURE NETWORKS

In the 1970's spatial equity played an important role in regional development policies in European countries. It was generally hoped that concentrated infrastructure investments in lagging regions would reduce interregional disparities.
In the 1980's most countries show a different policy direction. Bottlenecks become evident in infrastructure in many urban areas. The emphasis in infrastructure policies shifts to the international level. European integration means that many other traditional instruments of national economic policy lose importance. Infrastructure is increasingly considered as a major instrument for national governments which want to ensure that the national economy is strong enough to face international competition.
Regional equity considerations have become less important in the national policies of the 1980's. Some countervailing force has been exerted by the EC which has launched the European Fund for Regional Development (EFRD) for lagging regions which has a strong infrastructure component.

Another theme which has gained importance concerns the international level. The planning of infrastructure networks in the past was dominated by national perspectives. In the 1980's the international perspective started to play an important role. This can be seen for example from the Euro tunnel project connecting France and the UK, plans to improve Denmark's connections with Sweden and Germany and the plans to extend the French TGV network to Belgium, Germany and the Netherlands.

Rail related investments are remarkably dynamic during the last decade. It is expected that this will continue to be so during the next decades. This will reinforce the position of the large cities of Europe for two reasons. The first reason is that transport systems in larger urban agglomerations will be improved by the (further) introduction of light

rail. The second reason concerns the introduction of high speed rail connections which will favour large cities because demand is highest there. These rail investments have a polarizing impact on spatial development One should not exaggerate this impact, however, since investments in road continue to be much bigger than investments in rail all over Europe. Because of the high level of spatial penetration of the road network, investments in roads usually have a depolarizing impact on spatial developments.
A similar pattern of countervailing forces can be observed for two other types of communication infrastructure: airports and telecommunication. Both have been very dynamic during the last decade because of their economies of scale, the number of airports in space will be limited which will have a polarizing impact on spatial development. Telecommunication on the other hand is a system with ubiquitous access which offers opportunities to all regions.

3. SPATIAL MODEL OF INFRASTRUCTURE SUPPLY

Regions differ substantially in the amount of network infrastructure available to them. In the present section we will formulate a model on the supply of the highway and railway network. For both networks the main actor functions at the national level. It is the national governments which directly or indirectly (via the national railway company) decides on the shape and spatial distribution of these networks. For railways it has not always been like that. In the nineteenth century, railwaylines started to be supplied by private companies with a regional orientation. But in most European countries it did not take much time before national governments started to control or nationalized the railway companies.

The regional supply of network infrastructure will be measured in terms of the length of the network (in km) per km^2 per area of the region. One would of course like to take into account the capacity per link, (e.g., the number of lanes of a highway), but data on capacities are not available at a European level. The supply of infrastructure concerns a stock which usually has been developed over a long time. For example, most of the current canal system in Europe dates back to the first half of the 19th century. For rail the historical component is also considerable.

When modelling the regional supply of network infrastructure the following factors are assumed to influence network density:

- regional demand
- interregional demand
- possibilities of finance
- costs
- barriers

Network infrastructure serves both regional and interregional demand. The relative importance of the two depends of course on the spatial scale considered and the type of infrastructure. For roads the regional demand is usually dominating: the large majority of road network users only make short distance trips. Demand will be measured by means of population density. It is expected that high population densities induce high network densities. There may be reason to investigate a non-linear relationship between the two since high densities may give rise to relatively low distances travelled per inhabitant, and hence to a relatively smaller infrastructure need.
From a theoretical viewpoint one might prefer to use car density as a representation of demand for infrastructure. However, regional data on car ownership are not complete at a cross national level.

Possibilities of finance will play a role in the supply of network infrastructure. As indicated in Button and Rietveld (1992), the ways of funding infrastructure are rather different among European countries but a common trend towards a stronger involvement of the private sector is evident. In the present study we will use the level of gross domestic product per capita as an indicator of finance possibilities. It depends on institutional factors whether it is the national or the regional level of GDP per capita which is most relevant as a determinant of regional infrastructure density. In most European countries the planning of the highway and railway system involve the mobilization of funds at the national level (cf. Stoffelsma, 1992), so that one would expect that the national GDP per capita is the most appropriate candidate.

Costs of construction and maintenance may play a role in the supply of infrastructure. These costs have a national component (e.g., related to the level of labour costs in a country) and a regional one. Regional physical conditions (e.g. presence of mountains) may make construction so expensive that priority is given to other regions where conditions are more favourable. In our study we measure the costs by means of a dummy variable: regions where the highest altitude is at least 2000 m receive the value 1, other regions receive the value 0. One might prefer more refined data (e.g., on slopes) in this context, but this appears to be difficult to obtain at this regional level.

Barrier effects on infrastructure densities may occur for both physical and non-physical reasons. An example of a physical barrier is water. A region bordering on sea will have less need for transit traffic by road or rail. Thus, one would expect that its infrastructure density is lower compared with other regions. A countervailing force may be that regions with major sea ports need a high infrastructure density for the road and rail part of the logistic chain.

National borders are an example of non-physical barriers to infrastructure networks. One may expect that the lack of international coordination in the planning of infrastruc-

ture networks as well as the relatively low demand for cross-border mobility of the past has led to a neglect of infrastructure development in border regions.
On the basis of the above considerations, we have formulated the following equation for the supply of infrastructure per region:

$$INF/AREA = a_o + a_1\,(POP/AREA) + a_2\,(POP/AREA)^2 + a_3\,(GDP/POP) + a_4\,COST + a_5\,SEABOR + a_6\,(NTLBOR)$$

where:

INF/AREA:	regional infrastructure density of railroads or highways (km per square km)
POP/AREA:	regional population density (persons per square km)
GDP/POP:	regional or national gross domestic product per capita
COST:	dummy variable which attains the value 1 when the highest altitude in a region is at least 2000 m, and which is zero in all other cases
SEABOR:	share of total border of a region which borders to sea
NTLBOR:	share of total border of a region which is also a national border.

The coefficients a_1 and a_3 are expected to be positive. The other ones (except a_0) are expected to be negative.

An alternative formulation where infrastructure demand in neighbouring regions is taken into account in a more complete way would be:

$$(INF/AREA)_r = a_0 + a_1\,(POP/AREA)_r + a_2\,(POP/AREA)^2{}_r + a_3\,(GDP/POP)_r + a_4\,COST_r + a_5 \sum_{r' \epsilon S_r} sh_{r'}\,(POP/AREA)_{r'}\,b_{r'}$$

Where S_r is the set of all regions contiguous to region r. The factor $sh_{r'}$ is the share of region r' in the total border length of region r. When a region borders on the sea, the corresponding population density in r' is set equal to zero. The factor $b_{r'}$ is added to take into account the influence of a border effect. If r and r' are part of the same country, $b_{r'}$ is equal to 1. If r and r' are separated by a border it is equal to a factor b which is expected to be smaller than 1.

The last term of the above equation can be rewritten as:

$$a_5 \sum_{r' \epsilon S_r} sh_{r'}\;(POP/AREA)_{r'}$$
$$+(b-1)a_5 \sum_{r' \epsilon T_r} sh_{r'}\;(POP/AREA)_{r'}$$

where T_r is the set of regions contiguous to region r which are located in another country (T_r may be empty). The first part of the above formula describes the impact of all contiguous regions (including the sea and foreign regions), whereas the second part describes the impact of national borders.

Since b is expected to be smaller than 1, the contribution of the last term to infrastructure supply is expected to be negative.

4. ESTIMATION OF INFRASTRUCTURE SUPPLY MODEL

In our analysis we used Eurostat data. Table 1 contains results for a selected number of European regions defined at the NUTS-II level. The table shows that there is a clear relationship between population density and infrastructure density. In all countries considered, regions with a low population density tend to have a low infrastructure density. Difference between countries are clear: highway densities in the Netherlands, Belgium and Germany are high compared with France, Italy and Spain. The differences between regions are clearly smaller for rail densities than they are for highway densities. This may be related to the difference in life cycle betwen rail and road (cf. Grübler and Nakicenovic, 1991).

Table 1. Infrastructure densities in a selected number of regions (1984)

	highway density (m per km^2)	rail density (m per km^2)	population density (persons per km^2)
Ile de France	35.3	139.9	852
Basse Normandie	3.1	65.3	78
Nordrhein Westfalen	57.8	157.3	490
Bayern	26.8	100.1	155
DDR (former)	15.6	127.2	152
Lombardia	22.8	64.4	372
Basilicata	2.7	35.7	62
Cataluna	15.6	42.1	189
Andalucia	1.3	23.5	76
Brabant	77.1	160.2	661

West Vlaanderen	53.6	96.3	348
Zuid Holland	80.8	107.4	940
Drenthe	28.3	39.9	161

The infrastructure supply functions formulated in the preceding section have been estimated for 92 regions in the following countries: France, Germany, Italy, Spain, Portugal, Netherlands, Luxembourg and Belgium. A detailed account of the data is given in Boonstra (1992). Estimation results are given in Table 2.

Table 2. Regression analysis of railway and highway infrastructure supply in European regions (1984)

	railway density		highway density	
- constant	-10.3		-12.7	
- population density	110	(5.45)*	120	(10.41)
- population density squared	4.6	(0.41)	-33	(-5.37)
- gross domestic product per capita	.66	(7.80)	.15	(3.30)
- cost dummy	-17.5	(-3.21)	-2.20	(-.74)
- share of regional border which is national border	16.2	(1.43)	12.9	(2.10)
- share of regional border which is sea border	-27.6	(-2.24)	(-5.87)	(-.87)
R^2	.84		.79	

* t-values in parenthesis

Most of the factors mentioned above appear to play a role in infrastructure supply. For both railways and highways the intraregional demand as expressed by population density exerts a clearly stimulating impact on infrastructure supply. A non-linear relationship between population density and infrastructure density is found for highways: in densely populated regions, highway supply is smaller than one might expect on the basis of a linear relationship. This may be a reflection of the fact that car use in urban areas is lower than in rural areas, because car ownership is lower and trip distances are shorter because cities are more compact.

Another possible explanation is related to the measurement of infrastructure capacity. We did not take into account the number of lanes of highways, only their length. Therefore highway density does not fully reflect differences in capacity since the number of lanes of highways is higher in urban areas than elsewhere. This measurement problem may be captured by the squared population density term.

Gross domestic product per capita, measured at the national level is also a significant explanation factor of infrastructure density. If one uses the regional GDP per capita instead of the national one, a less significant result is found: infrastructure investments in highways and railways are clearly financed by a pooling of investment funds at the national level.

Two indicators of interregional aspects of infrastructure are taken into account: the share of the regional border which is also a national border, and the share which is also a sea border. The result for the seaborder has the expected negative sign, but it is only significant for railways. Thus, regions bordering on the sea have lower railway densities because there are no border crossing railway lines in certain spatial directions.

It is remarkable that the estimation for regions bordering to other countries does not yield the expected negative result. It appears that there is a negative barrier effect of national borders: for highways even a significant positive border effect is observed. Thus there is no evidence that European border regions are handicapped by a lagging supply of infrastructure. Even the reverse seems to be true. One important factor which helps to understand this result is that the regions taken here are large. For example, the region of Nordrhein Westfalia is one of these regions with a national border share of 25%. Obviously, one would not tend to consider this large region as a typical border area. One would expect, therefore that when a system with smaller regions would be used one would find clearer signs of border effects (this is confirmed in Rietveld, 1992). This consideration of regional size can only explain why border effects are not significant, but not why they have the wrong sign. Therefore, we are left with an intriguing result. Another possible explanation of this result is that borderregions may be underdeveloped regions which receive special support from national government and the EC for road and rail investments. Indeed, it is true, that border regions may be underdeveloped, but as can be seen from the pattern of expenditures of the European Regional Development Fund, there is not a clear correlation between border regions and development regions (cf. Armstrong and Taylor, 1985). For example, most Italian, French and Spanish underdeveloped regions are not border regions. A test with a model specification in which a variable is added to indicate regions receiving special EC support did not yield significant results for the pertaining variable.

Cost considerations appear to play a role in infrastructure supply: for railways high altitude regions have a lower infrastructure density than other regions. Also for highways a negative sign is found for the cost dummy, but it is not significant.

Estimation results for the alternative formulation mentioned in the preceding section are presented in Table 3.

Table 3. Regression analysis of railway and highway infrastructure supply in European regions, alternative formulation (1984)

	railway density		highway density	
- constant	-19.7		-13.3	
- population density	100	(4.42)*	102	(9.08)
- population density squared	11	(0.88)	-23	(-3.99)
- gross domestic product per capita	.67	(7.23)	.10	(2.39)
- cost dummy	-13.8	(-2.40)	.12	(0.04)
- population density in all neighbouring regions	31	(1.09)	50	(3.93)
- population density in neighbouring foreign regions	53	(1.02)	41	(0.60)
R^2	.82		.83	

* t-values in parenthesis

Most of the results in Table 3 are consistent with those of Table 2:

- The coefficient of population density is positive and significant for both modes,
- The coefficient of the squared population density is negative and significant for highways

- Railway supply is relatively low in high altitude regions where construction costs are high.
- The border effect is positive for both modes. A difference is that this effect is no longer significant for the alternative specification.
- The most notable difference in results is found for the population density in neighbouring regions variable. For highways a positive and significant coefficient is found. This variable is to a certain extent related to the seaborder variable used in Table 2 since a seaborder implies a zero density for the relevant neighbouring region. In Table 2, it was the railway system for which this variable appeared to have a significant impact.

The estimation results indicate that regional infrastructure supply for both railways and highways depend in a significant way on intraregional demand (as expressed by population density) and on possibilities of finance as measured by GDP per capita at the national level. Cost considerations play a significant role for railway supply. Interregional demand (as expressed by population density in neighbouring regions has a significant impact for rail or road, depending on the specification chosen. An intriguing result is that border effects are positive, though not always significant. This means that at the spatial level chosen here border regions are on average not suffering from any lack of infrastructure, one would rather say that the oppositie is true.

5. INFRASTRUCTURE SUPPLY WITHIN BORDER REGIONS

The empirical results shown in the above section indicate that at the NUTS II level, regions which are located at national borders do not suffer from low infrastructure densities, rather the opposite seems to be true. A possible explanation is that the regions considered are too large. When the analysis would be carried out at a smaller spatial scale so that border regions only include area near to national borders one would expect a negative effect on infrastructure densities.

In order to test this we have used data on Dutch border regions. The 7 regions (provinces) concerned have been divided into two parts: one part consists of all municipalities located at the national border, the second part consists of the rest of the provinces. Table 4 contains some results for relevant indicators.

An interesting result is that population density in municipalities at the border is on average not lower than in the rest of the border province. The median value is 109. Especially Drenthe and Limburg have high density municipalities at the border (all relative to the rest of the province). The median value for income per capita is slightly below 100 (98.8). Intermunicipality income differences are small in the Netherlands.

Intermunicipality infrastructure differences are much bigger, however. The median values for highways and railways in border municipalities relative to the rest of the province are 46 and 29, respectively. Thus, although the border municipalities have a slightly above average population density, their infrastructure densities are clearly below average.

Table 4. Indicators for infrastructure supply in municipalities located at national border relative to the rest of provinces in the Netherlands

	index for municipalities located at national border relative to rest of province			
province	population density	income per capita	highway density	railway density
Groningen	39	98.8	46	0
Drenthe	218	97.0	137	0
Overijssel	121	96.2	35	29
Gelderland	109	96.5	24	47
Limburg	171	100.9	172	104
Noord-Brabant	55	100.4	81	50
Zeeland	103	104.1	0	0

This result for the Netherlands strongly supports our expectation that border regions defined as municipalities located at borders indeed have low infrastructure densities. This disadvantage entirely disappears when border regions are defined in terms of the much larger spatial units at the NUTS II level. Thus negative border effects do exist in the field of infrastructure supply, but only at a relatively small spatial scale. This negative impact of low infrastructure supply in border municipalities can be felt in three ways. First in intra-regional transport in border regions. Second in border crossing interregional transport. Here, large detour factors may be expected, especially for trips which would be short could they have been made as the crow flies. Third, border municipalities will also have relatively bad connections with the other regions in the own country. Here too detour factors will tend to be larger than average.

6. CONCLUDING REMARKS

When analyzed at the NUTS II level, the supply of infrastructure depends mainly on two determinants: regional demand as represented by population size, and financing possibilities measured by the gross domestic product in the pertaining nation. The role of interregional differences in construction costs is less prominent, but this may be caused by the rather crude way in which this was measured. The spatial autocorrelation which may be expected to be relevant in an analysis of network densities has a rather limited role. At this level of spatial aggregation the impact of surrounding regions is not always significant. It is also remarkable (and difficult to explain) that border regions, when defined at this spatial level do not suffer from a lack of infrastructure supply compared with other regions. From Table 2 we infer that the negative impact on infrastructure supply for a region of being located at a sea coast is much clearer than the impact of being located near a national border. An analysis at a much more detailed spatial level reveals that national borders do have a negative impact on infrastructure densities, but that this is limited to a relatively small area near the border.

An interesting direction of future research is the development of a dynamic model of network supply. This would entail the use of spatial diffusion models for networks.

REFERENCES

Armstrong, H. and Taylor, J. (1985). *Regional Economics and Policy*. Philips Allan, Oxford.

Boonstra, J. (1992). *Barrieres in verkeer en infrastructuur; een internationaal perspectief.* Economische Faculteit, Vrije Universiteit, Amsterdam.

Button, K. and Rietveld, P. (1993, forthcoming). Financing urban transport projects in Europe. *Transportation.*

Dupuit, J. (1844). *De la mesure de l'utilité des travaux publics*, Annales des Ponts et Chaussées. an English translation appeared in: On the measurement of the utility of public works, International Economic Papers, no. 2, 1952, pp. 83-110

Grübler, A. and Nakicenovic, N. (1991). *Long waves, technology diffusion and substitution*. International Institute for Applied Systems Analysis, Research Report, 91-17.

Rietveld, P. (1992). *International transportation and communication networks in Europe; the role of barrier effects*. Department of Economics, Vrije Universiteit, Amsterdam.

NOTEN

1. Vakgroep Ruimtelijke Economie van de Vrije Universiteit te Amsterdam.