Yugoslav Journal of Operations Research
16 (2006), Number 1, 67-83

SPATIAL INFRASTRUCTURE AND PRODUCTIVITY IN SWEDEN

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Received: February 2005 / Accepted: May 2005

Abstract: Infrastructure consists of durable resources that are classified as "collective goods" generating external effects. The purpose of this paper is to analyse the role of spatial infrastructure on the industrial productivity in Sweden by utilising two complementary approaches: A non-parametric approach - Data Envelopment Analysis and a parametric approach – Production Function.

These approaches are applied to a cross-section data set of regions in Sweden. These approaches show that metropolitan regions have relatively low road efficiencies in comparison with other regions in Sweden. On the other hand the northern regions are more efficient than the southern regions.

Keywords: Infrastructure, productivity, Data Envelopment Analysis (DEA), production function.

1. INTRODUCTION

The development of income and standard of living in a society is highly dependent upon its productivity. During the last decade the productivity growth has been stagnating in the western industrial countries thereby reducing the base for private and public consumption. A common characteristic of the industrial countries is that a diminishing percentage of GNP has been allocated to public investments leading to a reduced growth of the infrastructure stock. Recent research shows that the productivity slow-down to a substantial extent can be explained by the reduced investment rate in public infrastructure, see e.g. Aschauer (1989), Berndt and Hansson (1991), Gramlich (1994), De Haan, Sturm and Sikken (1966), Seitz (2001). In this context we should make a distinction between material and non-material infrastructure. Non-material infrastructure includes the existing technological and organisational know-how and social networks. The material infrastructure on the other hand is defined as all the physical networks for transportation and communications, i.e. roads, railways, airports, harbours, constructions for post- and telecommunications, water and energy supplies.

The importance of different elements of the infrastructure will vary between countries and regions depending upon, e.g. geographical conditions, levels of economic development and sectorial mix of industries. It is important to point out that although the link between economic growth and infrastructure investment is strongly accepted, there are divergent opinions about the quantitative evaluation of this link. The significant contribution of Aschauer (1989) had a lasting impact. Berndt and Hansson (1991), Conrad and Seitz (1994), Nadiri and Mamuneas (1994) verified the productivity effects of infrastructure. However, Holtz-Eakin (1994) and Hulten and Schwab (1997) suggested no significant contributions of infrastructure to economic growth.

The two studies presented in this paper analyse the productivity effects on the manufacturing industry of investments in road capacity in Sweden.

The purpose of this paper is to analyse the role of spatial infrastructure for the development of industrial productivity in Sweden by utilising two complementary approaches:

1. A non-parametric approach by using Data Envelopment Analysis (DEA)
2. A parametric approach by using a Cobb-Douglas production function

These approaches are applied to a cross-section data set referring to regions in Sweden. The data set contains infrastructure as well as industry specific variables.

Section 2 presents some facts about public infrastructure in Sweden. In section 3 we give a short survey of the most important contributions in infrastructure literature as well as a discussion of theoretical modelling of productivity. Section 4 presents input data used in the analyses. The application of the non-parametric approach is reported in the section of Section 5, while the results of the application of the parametric approach are given in section 6. Finally, in section 7 the results of the two approaches are compared and explained.

2. SOME FACTS ABOUT TRANSPORTATION INFRASTRUCTURE IN SWEDEN

In the last decades a decreasing part of GNP has been allocated to public investment, i.e. formation of public infrastructure, in Sweden as well as in many other Western countries. From 1970 to 1996 this share decreased from close to 5 per cent to 2 per cent (see Figure 1). Public investment in transport and communication infrastructure was reduced from about 8 billion SEK in 1970 (1980 prices) to approximately 6 billion SEK in 1988. Furthermore a decreasing part of the public investments has been road investments. The effect of this stagnation is that the annual road investments in Sweden in real terms have been halved since mid-sixties; in 1980 prices they decreased from 4 billion SEK to 2 billion SEK. Due to changes in the statistical classification it is impossible to get this type of information for more recent years. However, the situation has not been improved in the last decade.

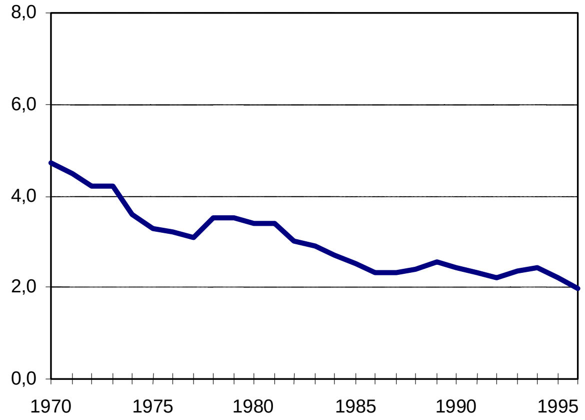

Figure 1: Public investment as a percentage of GNP in Sweden

Berndt and Hansson (1991) have estimated that the private business sector capital stock in 1988 was 817 billion SEK, while the public infrastructure capital stock was 355 billion SEK, i.e. approximately 43 per cent of the private sector stock.

3. INFRASTRUCTURE MODELLING

3.1. The parametric approach

Since the mid-eighties there has been a growing interest in studies of the relationships between infrastructure and productivity. In several studies economists have proved a distinct relation between accessibility to public capital and economic growth using an aggregated production function. An important conclusion derived from the studies is that increased investments in infrastructure will increase productivity of private capital and thereby stimulate private capital formation (Aschauer 1989, Peterson 1989). However, in order to entirely understand the productivity effects of infrastructure one cannot disregard the regional allocation of the infrastructure capital stock. These aspects have recently been analysed in a number of multi-regional studies (Anderson, Holmberg and Ohlsson (1990), Andersson, Anderstig and Hårsman (1990), Anderstig and Mattsson (1989), Johansson et al (1991).

Another interesting approach was proposed by Diewert (1986) and Seitz (1993). They used a restricted profit function to determine the net benefits of private firms obtained from access to public services in Germany. In the contribution of Berndt and Hansson (1991), a dual cost function has been used to prove that increases in public infrastructure capital, ceteris paribus, reduce private sector costs in Sweden.

A third approach is the vector auto regression approach (VAR). In a VAR model a limited number of variables is distinguished that are explained by their own lags and lags of the other variables, and Granger-causality tests are carried out (Sturm, 1998).

A common characteristic in the infrastructure literature is that of production function formulation relating value-added output Q to the quantities of input L, private capital input C_p and public infrastructure input C_i.

If the parameters of this formulation of production function are estimated, this method is called the parametric approach. The following production function is a typical parametric application, where the parameters are estimated by the use of econometric techniques.

$$Q = F(L, C_p, C_i) \tag{1}$$

Various specifications of the production function have been used. The Cobb-Douglas function is still the most frequent specification. More complicated functions have also been applied, like the translog function and the Mills and Carlino formulation (1989).

However, a number of infrastructure studies may be found where public infrastructure capital C_i has not been incorporated in their production or cost functions. An obvious implication of this misspecification where the C_i is an omitted variable is that all the empirical results may suffer from an omitted variable bias. A recent study of Wibe (1992) for the Swedish infrastructure is an example of this way of thinking.

In the non-parametric approach the parameters of the production function are not estimated, but relative efficiency indices are calculated reflecting input-output differentiation between various units.

A comparison of parametric and non-parametric deterministic efficiency measures has been attempted by among others by Banker et al (1986) and Ferrier and Lovell (1990).

A conclusion of these papers was that the compatibility of the parametric and non-parametric approaches was rather unsatisfactory but that the future development seemed to be promising.

Another approach to estimate the economic effects of infrastructure investments is the Cost Benefit Analysis (CBA). In the CBA the economic effects of an infrastructural investment are measured as increases of the consumer surplus of the estimated transport demand function. This means that the technique presupposes that all the effects of the investment are reflected in the transport sector. Since this paper deals exclusively with the influence of spatial infrastructure on industrial productivity, the CBA is not the appropriate technique for this problem.

3.2. The non-parametric approach

In this section, the following method will be presented, which can handle the efficiency evaluation puzzle: Data Envelopment Analysis (DEA). A mathematical programming model applied to input-output data gives estimates of extreme input-output relations like the production function. The name DEA derives from the procedures applied to observational data, which are used to establish efficiency frontier via an envelope function of all production processes. The concept DEA was introduced in the journal literature by the highly influential 1978 paper of Charnes, Cooper and Rhodes (CCR). However, studying the diffusion of ideas may give valuable insights into research issues still unexplored and insight in the research process itself. In CCR a key inspiration is the paper "The measurement of productive efficiency" by Michael Farrell (1957). The fundamental assumption was the possibility of inefficient operations, immediately pointing to a frontier production function concept as the benchmark, as opposed to a notion of average performance underlying most of the econometric literature on the production function up to the time of the seminal contribution.

An organisation (a region in this study) is considered to be efficient, if and only if there does not exist a linear combination of organisations, which dominates the given organisation.

We are aware of the "heterogeneity problem" of our data set due to differences in industrial composition in our regions and other factors, but we do not consider this a serious problem in the present study. However, we know of many empirical DEA applications where this problem has been addressed either by ignoring the problem altogether or by constructing homogeneous groups to perform the analysis on (cf. Førsund & Kalhagen 1999).

As a consequence, it is a mathematical programming problem to find the most dominant linear combination if such one exists. If the resulting indexes for a given organisation have an efficiency ratio of one, then the organisation is said to be efficient.

If, on the other hand, the efficiency ratio is less than one, the organisation is said to be inefficient relative to the other organisations of the study.

DEA draws an envelope over the scatter plot, highlighting an"efficient production frontier". The procedure is illustrated in the following diagram (Figure 2).

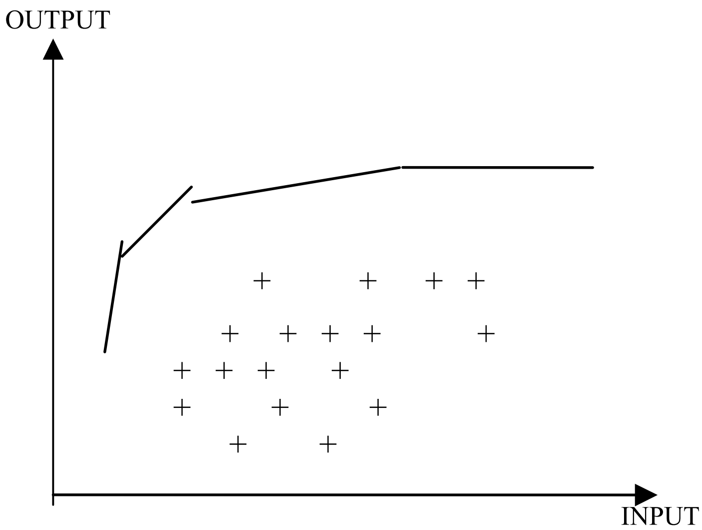

Figure 2: An illustration of the DEA procedure.
The DMUs (Decision-Making Units) on or near this curve are the efficiency leaders, and are worthy of emulation by their less efficient neighbours.

This method has been used in USA for evaluation among others, schools, hospitals, courts, traffic regulation etc. For an introduction see Charnes, Cooper, and

Rhodes work (1978, 1981) or Bessent et al (1982), or Sarafoglou and Haynes (1990, 1996), Seiford (1996), Førsund and Sarafoglou (1999, 2002).

Let *k* indicate the organisation, which will be investigated for dominance of the reference set with which it is being compared.

The efficiency of this organisation is determined by means of mathematical programming as given by the following formulation:

$$\min z_k \tag{2}$$

Subject to:

$$j\sum X_{ij}l_j - X_{jk}Z_k \leq 0 \quad i = 1,2,3...n \quad j = 1,2,3...m$$

$$j\sum Y_{ij}l_j > Y_{ik}$$

$$l_j \geq 0$$

The x_{ij} represents parametrically given values for the *i*:th input of the *j*:th organisation, where y_{ij} represents the likewise parametrically given outputs obtained from these inputs. Borrowing from the natural science terminology, the variables l_j are named as virtual rates of transformation. They indicate also the linear combination of organisations, which will dominate the k organisation. Thus, the product x*l and y*l will be regarded as the virtual inputs and outputs.

The measure of efficiency *z* is scale independent in each of its inputs and outputs. The constraints in (2) ensure that the production unit will achieve an efficiency index positive but not greater than unity.

By applying the model (2) *N* times -once for each organisation- we get the efficiency index of each organisation as well as the l's variables.

There are many computer programs to solve the *N* linear programming models defined in (2) via a modified simplex method. A good description of these statistical packages may be found in Sharda (1984).

The basic advantages of DEA are:

1. It does not require the production function to be specified in parametric form a priori.
2. The resulting scalar of efficiency is obtained from LP methods, in which all inputs and outputs are explicit.

4. VARIABLES USED IN THE ANALYSIS

Many efforts have been made to define infrastructure. The most restricted definition is that, infrastructure can be identified from the following attributes:

1. Infrastructure is durable capital with fixed location, and its services have a spatial extension, although the benefits decline as distance increases.
2. Infrastructure services satisfy at least one of the following features: (i) polyvalence, (ii) temporal generality, (iii) systemic or network functions.

However, the most common definition is that infrastructure is a resource which can be utilised collectively by many firms and households. Thus infrastructure may be seen as a potential for communication between people and markets. In addition to this regional and development economists have argued that health and education of the population must be included in the definition of infrastructure (Hirschman 1958).

The independent variables included in our analysis are organised in four categories:

1. supply of qualified labour,
2. local and intraregional networks,
3. interregional networks,
4. industrial capital intensity, and
5. output of industry.

The first category of variables is related to the broader definition of infrastructure. The second and the third category are related to the most common definition of infrastructure. The fourth category is a non-infrastructure variable, which is routinely used in productivity studies.

1. Supply of qualified labour
    - The percentage of labour force with 12-years education (high school or equivalent).
    - The percentage of the "knowledge" generating occupation, i.e. teachers, doctors, engineers etc.
2. Local and intraregional networks
    - The primary supply of public transport system as measured by the product of number of places or passengers times kilometres in relation to the population or to the labour force. The population is a proxy for the market interaction.
    - The road accessibility measured as a weighted average of the travel distance by car between each one of the Swedish municipalities weighted by its economically active population.
    - The flow capacity of the road system in each region is defined as the road length time's width times stipulated velocity divided by the area of each region.
3. Interregional networks
    - Airport capacity as approximated by the number of flights or alternatively the number of passengers in relation to the population. In Sweden this measure closely reflects the actual capacity of the airports.
4. Industrial capital intensity
    - The capital intensity is the value of industrial buildings and machinery divided by the number of industrial workers.

The output or dependent variable in this study is labor productivity, i.e. value added per worker in the manufacturing industry.

Most data used in the study refer to the year 1985 and are collected from official statistical publications from Statistics Sweden. Data used in the calculation of road flow capacity is from the Road Data Bank, Swedish National Road Administration. One reason for not using more recent data is the problem of acquiring data on industrial capital with a regional subdivision. However, this study primarily addresses methodological issues, which to some extent justifies the use of the present data set.

5. APPLICATION OF DEA

The regional units in DEA are the 24 counties (län) in Sweden. Each county can be subdivided in labour market regions (A-regioner), which are aggregates of municipalities. The total number of these labour market regions is 70[1]. Earlier studies on the same subject (see Andersson et al, 1990), by using production function pointed out the 2 northernmost counties of Sweden as extreme observations. Following the same procedure here, these remote counties are excluded from the analysis also in this study.

The next step is to calculate the differentiation of regional efficiencies of the 22 counties in Sweden. By applying the DEA on input-output data of Sweden as it has been described in the previous sections, we get the efficiency ratings as presented in Table 1.

Table 1. Calculated DEA-efficiencies at the county level.

County	Efficiency index*	County	Efficiency index	County	Efficiency index
Kopparberg	1.00	Gävleborg	0.91	Stockholm	0.51
Skaraborg	1.00	Värmland	0.72	Älvsborg	0.51
Västernorrland	1.00	Örebro	0.70	Kristianstad	0.49
Jämtland	1.00	Uppsala	0.67	Södermanland	0.48
Gotland	1.00	Göteborg/Bohus	0.60	Kronoberg	0.46
		Malmöhus	0.57	Blekinge	0.44
		Kalmar	0.56	Jönköping	0.44
		Västmanland	0.55	Östergötland	0.40
		Halland	0.55		

* Regions with an efficiency index above 0.95 are regarded as efficient, between 0.94 and 0.55 of medium efficiency and below 0.55 as inefficient.

By observing these ratings, the following remarks can be made with regard to how infrastructure efficiencies vary between regions:

- As expected, counties with an relatively important industrial sector exhibit higher rates of DEA-efficiencies than counties where the tertiary sector is more important;
- The metropolitan regions have efficiencies at very low levels;
- The northern counties exhibit efficiencies at high levels;

[1] The counties and corresponding A-regions are listed in population publications from Statistics Sweden . With a few exceptions most A-regions belong to only one county.

6. THE PARAMETRIC APPROACH.

A large number of different models were estimated in this approach in order to evaluate the importance of regional characteristics (see e.g. Andersson et al. 1990 for an extensive review). The mathematical form of the estimated function finally chosen was as follows:

$$\ln(Q/L) = \beta_0 + \beta_1 \ln(C/L) + \beta_2 \ln(vfl) + \beta_3 \ln(ak) + \beta_4 (tfl) + \beta_5 (ak \cdot tfl)$$

Table 2 below shows the definition of each one of the variables and estimated parameter values of the function.

Table 2: Parameters of the estimated production function for Swedish Labour Market regions.

Variable	Parameter value (β_i)
Constant (β_0)	4.02
C/L = capital intensity	0.32 (7.45)
vfl = flow capacity of the road system	0.20 (3.79)
ak = percentage of "knowledge" generating occupations	-0.11 (-1.23)
tfl = airport capacity	3.07 (2.10)
(*ak* * *tfl*) = interaction term	-0.02 (-2.05)
R-square	0.51

Note: Values within brackets are t-values

Table 2 shows that capital intensity, flow capacity of the road system and interregional accessibility by air all has statistically significant positive effects on labour productivity in the manufacturing industry. The negative impact on labour productivity of innovation potential demands an explanation. A reasonable hypothesis is that an improved education the regional labour force should increase labour productivity.

However, since the increase of the number of university trained individuals has taken place during the last decade, and its effect on labour productivity in the manufacturing industry are of long-term character a negative may be possible. One may expect a positive interaction effect on labour productivity and innovation potential and interregional accessibility by air. From Table 2 it can be seen that the negative effect of innovation potential dominates the interactive effect. However, the introduction of the interactive effect strengthens the statistical significance of the remaining variables. The parameter value 0.20 of flow capacity means that an increase of flow capacity by 10 percent will increase labour productivity in manufacturing industry in Sweden by 2 percent. On the basis of the estimated production function we can derive the marginal rate of technical substitution (MRTS) of the flow capacity of the road net for industrial capital. The substitution ratio can be used as a measure of the rate of return of industrial investments. The higher ratio in a region the higher is the rate of return of industrial investments in that region. (See Appendix A for derivations).

Industrial capital is expressed in monetary units and road capacity in terms of physical units. Therefore, in order to make industrial capital and road capacity comparable we have to transform increases of road capacity into monetary units. The lifetime of road capital is approximately twice that of the industrial capital according to Swedish road authorities. Consequently the "critical" substitution ratio (expressed in monetary terms) of flow capacity for industrial capital is 2. This means that a substitution ratio lower than 2 in a region would indicate that road investment is more productive than industrial investments. Table 3 gives a classification of the Swedish Labour Market Regions according to the value of their substitution ratio[2].

Table 3: Classification of the 70 Labour Market Regions in Sweden according to the value of the substitution ratio of road capacity for industrial capital.

Substitution ratio	Number of Labour Market Regions
< 2.0	16
2.0 - 3.3	15
>3.3	39

As can be seen from Table 3 a quarter of the regions have substitution ratios which are below the critical value, i.e. investments in road capacity in these regions have a high marginal profitability. For another quarter of the regions (substitution ratios between 2.0 and 3.3) there is a balance between industrial and road capital. In these regions industrial investments need supplementary investments in road capacity in order to maintain the balance between industrial and road capital. The main part of the regions has a substitution ratio exceeding 3.3 which means that investments in industrial capital in these regions are more productive than investments in road capacity.

Table 4 shows the regions with the highest and the lowest substitution ratios between industrial and road capital. From the table can be seen that the road capacity is obviously insufficient in the three metropolitan regions Stockholm, Göteborg and Malmö. Several of the regions having high productivity of road investments are situated around Lake Mälaren and connected with Stockholm area. Table 4 also shows that expansion of the road capacity has low productivity effects within a bound of regions in the south-eastern part of Sweden. These regions are characterised by low rate of economic growth and population growth.

[2] A complete listing of substitution ratios for all A-regions can be found in Holmberg et al, 2002.

Table 4a: Swedish Labour Market Regions with the lowest marginal substitution ratios of road and industrial capital investment (highest return of road investment).

Labour Market Region	Substitution ratio	Labour Market Region	Substitution ratio
Karlskoga	0.27	Norrköping	1.43
Göteborg	0.76	Helsingborg	1.43
Stockholm	0.90	Avesta	1.47
Gävle	1.00	Västerås	1.56
Karlshamn	1.19	Eskilstuna	1.69
Köping	1.20	Fagersta	1.79
Trollhättan	1.28	Borlänge	1.84
Malmö	1.31	Skövde	1.96

Table 4b: Swedish Labour Market Regions with the highest marginal substitution ratios of road and industrial capital investment (lowest return of road investment).

Labour Market Region	Substitution ratio	Labour Market Region	Substitution ratio
Falköping	6.83	Enköping	12.48
Arvika	6.85	Sala	13.52
Växjö	7.28	Visby	14.05
Ystad	8.13	Mora	14.51
Haparanda	8.17	Västervik	14.85
Örnsköldsvik	9.14	Östersund	40.33
Ängelholm	11.36	Lycksele	42.54
Tranås	11.59	Sollefteå	131.65

7. COMPARISON OF THE TWO APPROACHES

The two models used in this paper differ inter alia with regard to their level of spatial aggregation. In order to make the two approaches comparable in this respect the results from the production function model have been aggregated from Labour Market Regions to counties. This is possible because both types of regions are with only a few exceptions made up of municipalities. In the following table the counties have been grouped according to the productivity of road investments.

Table 5: Classification of countries according to productivity of road investments from the production function approach.

Low productivity	Medium productivity	High productivity
Värmland	Blekinge	Stockholm
Kopparberg	Malmöhus	Halland
Älvsborg	Västmanland	Örebro
Kristianstad	Göteborg o Bohus	Gävleborg
Skaraborg	Södermanland	
Jönköping	Östergötland	
Uppsala		
Västernorrland		
Kalmar		
Kronoberg		
Jämtland		
Gotland		

As can be seen from Table 5, there are three times as many counties with low productivity as with high productivity of road investments. A high productivity of road investments would mean that industrial investments are less productive in relation to road investments. Consequently, in those provinces where road investments have low productivity, the productivity of industrial investments is high in relation to road investments and vice versa. The efficiency index numbers in Table 1 above derived from the DEA approach, are measures of productivity of industrial investments in the counties studied. By utilising Table 6 it may be seen that the results from the two approaches as comparable.

Table 6 gives a cross-classification of the results according to the two approaches. The comparison indicates that, by and large, they give the same result for this data set. Counties in which industrial investments are highly productive according to the production function approach (low productivity of road investments) also have high efficiency indices according to the DEA-approach. The differences of the results can be explained by the divergence of the spatial aggregation level and the fact that the DEA-study used more input variables than the production function application.

Some policy conclusions can be made from the two studies. The production function approach suggests that public investments in the road system should be allocated to regions showing high marginal productivity of the road capital; private investments in industrial activity on the other hand should be allocated to regions with low marginal productivity of the road capital. These policy conclusions are in accordance with the results from the parametric approach and from the DEA.

Table 6: Summary of the results from the DEA and the production function approach; efficiency indices of counties.

Production function approach	DEA		
	Low efficiency	Medium efficiency	High efficiency
Low productivity	Älvsborg Jönköping Kronoberg Kristianstad	Värmland Uppsala Kalmar	Kopparberg Skaraborg Västernorrland Jämtland Gotland
Medium productivity	Blekinge Södermanland Östergötland	Malmöhus Västmanland Göteborg & Bohus	
High productivity	Stockholm	Halland Örebro Gävleborg	

The compatibility of DEA and production function has not reached the ”maturity phase”, but we hope that our article is on the right direction.

8. CONCLUSION

The main value added of this article is to elucidate quantitatively the spatial infrastructure efficiency by using parametric (productions function) and non-parametric (DEA) approaches at different aggregation levels.

The empirical results may be seen as a partial confirmation of the suggestion that the two approaches are converging.

These approaches show that metropolitan regions have relatively low road efficiencies in comparison with other regions in Sweden. On the other hand the northern regions are more efficient than the southern regions.

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APPENDIX A: CALCULATION OF SUBSTITUTION RATIOS.

The final version (non-logarithmic form) of the estimated production function is given by:

$$\overline{Q} = \beta_0 \cdot \overline{C}^{\beta_1} \cdot (vfl)^{\beta_2} \cdot e^{\beta_3 \cdot (ak)} e^{\beta_4 \cdot (tfl)} e^{\beta_5 \cdot (ak \cdot tfl)}$$

where

$$\textit{where} \quad \overline{Q} = Q / L$$

$$\textit{and} \quad \overline{C} = C / L$$

and other variables as defined above (Table 2).

$$MPP_C = \frac{\partial \overline{Q}}{\partial \overline{C}} = \beta_1 * \frac{\overline{Q}}{\overline{C}}$$

Starting from this estimated production function the marginal productivity of capital and of the flow capacity of the road net can be derived according to the following formulas:

$$MPP_{vfl} = \frac{\partial \overline{Q}}{\partial (vfl)} = \beta_3 * \frac{\overline{Q}}{(vfl)}$$

Estimated values of the marginal productivities of the respective factors are obtained by using estimated values of the parameters β_1 and β_2 together with average values of *Q/L*, *C/L* and *vfl*.

As a basis for the calculations for the regions we assume that the estimated production function holds for every one of the regions in the country. This implies that what distinguishes the various regions is that varying quantities of labour and private and public capital are employed in the production process.

From the production function the marginal technical substitution ratio between two resources in a production process may be derived. Such a ratio tells us how two different resources can be substituted for each other. The marginal technical substitution ratio of the flow capacity of the road net for industrial capital can be calculated from their respective marginal productivities as:

$$MRTS = \frac{\partial\, (vfl)}{\partial\, \overline{C}} = \frac{MPP_C}{MPP_{(vfl)}}$$

For Sweden the following average values of the marginal product ivies are obtained for the country as a whole:

$$MPP_c = 0.32 \cdot 7578 / 6234 = 0.388$$

$$MPP_{vfl} = 0.20 \cdot 7578 / 54.99 = 27.56$$

The marginal technical substitution ratio for the country as a whole then becomes:

$$MRTS = 0.388 / 27.56 = 0.0141$$

This result implies that an increase of industrial capital by 1 million SEK can replace 0.0141 units of flow capacity of the road net. Furthermore, in order to increase the flow capacity by one unit in an average Swedish A-region, it is necessary to build approximately 12 kms of motorway of normal standard which would cost about 360 million SEK. Consequently, the actual substitution ratio is 5:1 or in other words: To compensate for an investment of one million SEK in industrial capital, roads need to be built for 5 million SEK.

Marginal substitution ratios vary considerably between the A-regions of Sweden, from slightly below 2 up to over 600 (cf. the accompanying table). Increasing the flow capacity of the road net by one unit is proportional to the total area of the region and since the flow capacity as well varies between regions it is impossible to predict the actual substitution ratio between investment in industrial capital and in the road net. Another factor that needs to be taken into account is the fact that investment in roads has a much longer life-length than investment in industrial capital.

According to Swedish road authorities the life-length of roads is roughly twice that of industrial capital, which means that the "critical" substitution ratio is 2. Thus, if an investment in road capital of 10 million SEK can replace an investment of at least 5 million SEK in industrial capital, the investment in roads is more profitable. Or in other words: *The less the substitution ratio is than 2 the more profitable is investment in the road net*.

Estimated values for A-regions of Sweden of marginal productivities and substitution ratios are given in Holmberg et al., 2002.