Improving on Africa's roads

Modeling infrastructure investment and its effect on subsistence agriculture*

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Abstract

Investment in infrastructure is considered as a crucial prerequisite for economic development. Given the scarce resources for public investment in developing countries a detailed perspective on the effects of each form of infrastructure is needed. This paper focuses on transport infrastructure in Africa. The effects of better and longer roads are investigated in a theoretical model, an empirical setup and in a Computable General Equilibrium (CGE) model. The effects on production, consumption and income distribution are shown. Most importantly the model is used to investigate the effect of roads on the economic participation of rural households.

The presented CGE model may be used as a toolkit for the investigation of different policy scenarios concerning the type and volume of investment as well as the possible financing alternatives. Robustness checks show that in order to provide reliable quantitative results much more information is needed about the exact value of particular parameters in the model.

JEL Classification: O11, O55, R42

Keywords: Infrastructure, General Equilibrium, Computable General Equilibrium, Transport networks, Africa, rural development, subsistence agriculture

*Preliminary version, comments are very welcome.

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"Rural infrastructure constitutes a substantial and growing component of Bank activities. Currently, over one-fifth of Bank lending in the rural sector is spent on infrastructure."

(World Bank Website on the strategy for Agriculture and Rural Development, December 2009)

"Transportation is an underpinning of economic growth. [...] Working on those networks, making them efficient, safe and reliable, is a path toward economic development and growth." (Thomas Barrett, U.S. Deputy Transportation Secretary, October 2008)

1 Introduction

Investment in infrastructure in general and in transport, water and energy in particular, is considered as a crucial prerequisite for sustainable economic development. This common belief is reflected in a strong emphasis of all donors, especially of those of multilateral aid, on the sectors energy, transportation, water and communication. World Bank lending to Africa for these sectors amounted to 3.3 billion fiscal 2009 US-Dollars which is a doubling of infrastructure aid since 2006. The developing world and especially the African continent has a very poorly developed and maintained infrastructure compared to middle and high income countries. In 2000 Sub-Sahara Africa had a road density of only approximately 30 meters of paved roads per km^2 compared to 1200 meters in high income countries. Electricity production in Sub-Sahara Africa amounted to 0.08 KW per capita which is only less then 4% of the 2.1 KW produced per capita in high income countries. [See Fay & Yepes, 2003] Only 60% of the population of Sub-Sahara Africa have access to clean water. The World Bank stresses that the situation is even worse in rural areas. Only 46% of rural households in developing countries have access to electricity compared with 89% of urban households. Only 12% of rural houses have in house water-taps while 59% of urban households have direct access to water. [See World Bank, 2009]

The importance of infrastructure has been stressed in the literature since the seminal work by Aschauer [1989]. For industrial countries it is clearly documented that investment in public capital increases the total factor productivity and has positive impacts on long-term output. [See e.g. Gramlich, 1994; Romp & de Haan, 2007, for comprehensive surveys of the literature.] In the development economics literature there is a number of studies concerning the effects of infrastructure on growth using replications of Aschauer's approach. However in the development economics literature the focus is on the effects from better roads on variables such as poverty and income distribution. [E.g. Calderon & Serven, 2008]

Infrastructure is a very broad concept and summarises a number of extremely different public and non-public goods and services. The term "infrastructure" comprises transport networks, water utilities, energy production and provision, the whole education system, the health care system, sewage, waste disposal services, telecommunication and public security. Some authors even include administration and jurisdiction. [E.g Jochimsen, 1966; Buhr, 2003; Torrisi, 2009]

This paper contributes to the existing literature by showing how infrastructure investment could be modelled in a general equilibrium setup and by integrating the dimension of market participation of rural households into the analysis. We make a clear distinction between the different forms of infrastructure and focus thereafter on transport infrastructure. This paper intends to push forward a more disaggregated perspective on infrastructure investment in developing countries especially on the effects of rural roads in Africa. Starting with a brief overview of the literature we present some theoretical reflections on the definition and classification of infrastructure. In the following sections we investigate the effects of increased investment in transport infrastructure by means of a stylized theoretical model, a cross-sectional empirical estimation and a calibrated Computable General Equilibrium (CGE) model.

In an empirical cross-sectional analysis of the influence of transport network density on the trade and transport margin, we confirm that better transport networks reduce transport costs. Using cross-sectional data for 53 countries from all over the world and controlling for a number of country characteristics it is shown that a higher road length reduces the agricultural trade and transport margin.

We develop a stylized general equilibrium model which integrates transportation explicitly into the supply function of a representative good. In this model setup with two goods, a consumption good and a transport good, one representative agent and two factors of production, it is shown that supply, production and consumption can be increased by means of reduced transport costs if transport infrastructure is improved. Easier transport of goods to markets frees up labour and capital for the use in production.

The stylized model and the results of the estimation are then combined in a CGE model which additionally includes multiple goods and households, international trade, subsistence agriculture, public investment as well as operation and maintenance (O&M) costs. The model is calibrated to a stylized African economy. General equilibrium analysis provides a good toolkit to investigate the aggregate and disaggregate effects of infrastructure investment on a sectoral basis. Though these advantages are obvious CGEs have not been used extensively in this field so far. Maybe due to severe data limitations most CGE studies are very aggregated and have rather strict assumptions. The complex setup of the calibrated CGE model presented here allows for the investigation of the effects of transport infrastructure on production, consumption and factor allocation. Most importantly the model permits the investigation of the effect of a better access to markets by means of better roads on the participation of rural households in the economy. The model allows for different assumptions concerning the division of the costs and benefits from infrastructure between the different household groups. It is shown that an increased quality and quantity of transport infrastructure increases welfare. Production and consumption rise at the aggregate and disaggregate level. However, the assumed efficiency of infrastructure provision as well as the size of O&M cost are crucial concerning the magnitude of these effects. The model could easily be calibrated to other more disaggregated data and be modified to include other forms of infrastructure. The last section concludes and specifies fields for further research.

2 Overview of the relevant literature

2.1 Definition and classification of infrastructure

Infrastructure is a heterogeneous concept as e.g. Calderon & Serven [2008] point out. The term infrastructure is most widely defined by Jochimsen [1966] as

> [...] the sum of material, institutional and personal facilities and data which are available to the economic agents and which contribute to realizing the equalization of the remuneration of comparable inputs in the case of suitable allocation, that is complete integration and maximum level of economic activities.

Even narrowing the definition to only material infrastructure as Buhr [2003] does:

> [Material] infrastructure is understood to represent capital goods in the form of transportation, education and health facilities, equipment of energy and water provision, facilities for sewage, garbage disposal and air purification, building and housing stock, facilities for administrative purposes and for the conservation of natural resources.[...]

leaves us with a number of different aspects to be considered.

Other studies use a substantially narrower definition of infrastructure like e.g. Estache [2006]:

> [...] infrastructure is defined here as all the facilities used to deliver energy, water and sanitation, telecommunication and transport services.

Not all of the elements of infrastructure are goods, there are also services and immaterial components. Furthermore, not all of these are provided publicly nor are they public goods in general. It should also be mentioned that many of these components do not fall into the category of investment. The widely-used approach to analyse infrastructure by only investigating public investment does not suit the concept of infrastructure appropriately as e.g. Calderon & Serven [2008] emphasize. Nonetheless even in the theoretical literature *public capital* and *infrastructure* are often used as synonyms, like e.g. in Gramlich [1994]:

> Public capital consists of large capital intensive monopolies such as highways, other transportation facilities, water and sewer lines and communication systems.

It is obvious that not all of the above mentioned components of infrastructure work in the same way in promoting growth and reducing poverty. While education and health are especially efficient in improving the productivity of labour, law and security promote the efficient allocation of capital. Energy and water are intermediate inputs in production while transport and communication improve the access to markets. This variety of effects shows that the frequently used approach to measure infrastructure by using the perpetual inventory method is very limited in capturing all dimensions of infrastructure. Given the fact that resources for large scale investment in infrastructure are scarce in most developing countries, it is important to have a detailed picture about the distinct effects of each infrastructure category. In addition some infrastructure investments give rise to high O&M cost which should be taken into account, too.

In this paper infrastructure is defined following Estache [2006] only comprising electricity, water, telecommunication and transport. Among these components we will concentrate on transportation infrastructure i.e. roads, railways and ports. We will show how to model its effects in suitable general equilibrium model.

2.2 Previous studies on transport infrastructure

As infrastructure is a very broad concept there exists a large variety of literature dealing with its effects. The literature is very heterogeneous in terms of what kind of infrastructure is analysed and which outcome variable is considered. There exist several detailed surveys of the literature e.g. by Gramlich [1994]; Buhr [2003] and more recently Romp & de Haan [2007]. The following very brief summary of the relevant literature only includes the main strands of the transport literature and even more specifically the studies on the effects of transport infrastructure improvements in developing countries.

Most macroeconomic studies on the effects of infrastructure follow the so-called production function approach. They estimate a national production function where GDP or growth depend not only on labour, capital and technology but also on public capital. Public capital is normally measured by aggregating past public investment flows, the so-called perpetual inventory method. This approach has been applied to developed and developing countries, to time-series, cross-sectional and panel data and there seems to be a consensus on the positive effect from public capital on output even though the magnitude of this effect is disputed. Most of the recent literature in this strand is more or less based on the work by Aschauer [1989] who applied the method to U.S. time series data. It has been applied to cross-sectional data including developing countries by Hulten [1996]; Ram [1996] and many others. Hulten and also Aschauer [2000] emphasize that not only the volume of infrastructure provided but also the efficiency of its use are important. Still the methodology is only capable to investigate the effect of public capital as an entity instead of the effects of distinct forms specifically.

For developing countries output is not the only relevant outcome to be taken into account. Estache [2006] summarizes the macroeconomic literature on infrastructure (here defined as energy, water, waste disposal and transport) and development (i.e. growth, poverty, education, sanitation and health) and points out that even though

> [...] since the late 1980s over 150 published papers in English, French or Spanish and at least as many unpublished ones have analyzed the macroeconomic effects of infrastructure [...]

there is still a large knowledge gap especially due to limitations in the fields of data collection, evaluation of existing projects and accountability. Estache concludes that concerning the macroeconomic growth effect the findings are positive nonetheless concerning poverty and distribution there is less evidence available. Njoh [2000] emphasizes that the link between infrastructure and development has been investigated mainly for the industrial countries in the 1950s and in form of country studies. Nonetheless, he underlines the specific importance of the subject for developing countries and claims that most papers in the field of development economics present theoretical investigations and no empirical evidence. The findings from cross-country studies concerning poverty and distribution and its correlation with infrastructure suggest that the poor and rural population should be targeted specifically as it could not profit from past infrastructure projects. [See Bryceson *et al.*, 2008]

A completely different strand in the macroeconomic literature focuses on the trade effects of better transport networks. Using gravity models, this literature investigates the tariff equivalent costs of poor roads on international trade. Unfortunately, disaggregated data for developing countries is very limited and prohibits disaggregated studies especially for rural areas in Africa and the possibility to access local markets. Most studies in this field concentrate on international trade instead of interregional trade and include only international corridors into their transport aggregate leaving the important notion of rural infrastructure aside. Examples are Yeats [1980], Limao & Venables [2001] and more recently Portugal-Perez & Wilson [2008].

In addition to the considerable macroeconomic literature there exists a variety of country and case studies evaluating specific projects or programmes. The focus of these studies is mostly on the effect of better roads on variables such as poverty, employment and access to markets. Examples are Olsson [2009] who analyses the Philippines, Escobal & Ponce [2002] who compare three African countries, Fan *et al.* [1999] for India or Fan *et al.* [2004] for Uganda. These studies provide promising evidence about the overall positive effect of infrastructure especially on rural development. For all of these countries it has been found that especially rural roads provide an instrument to reduce rural poverty and promote growth. It seems that a reduction in transport costs is by far not the only positive outcome of enhanced roads. The direct effect on transport costs and travel times may be considered as the lower bound of the overall positive welfare effect.

Against the background of the presented macro- and microeconomic approaches a CGE study is not limited to only one specific outcome variable. Such a model shows the effects of a specific policy experiment on the aggregate and sectoral output but also on income distribution, welfare and factor allocation. Furthermore it allows to distinguish direct and second round effects and it provides a clear counterfactual. Different scenarios concerning the financing of transport investment could be simulated and different assumptions on O&M expenditure included. Nonetheless there is only a very limited number of studies in the field, namely Agenor *et al.* [2008] and Adam & Bevan [2006]. While Agenor *et al.* [2008] explicitly model all different forms of public capital and the effects of all of them, their model is very limited in other respects, most importantly it has only one representative household and only one aggregate good. Adam and Bevan's model on the other hand is somewhat more disaggregated with respect to the number of sectors and contains a number of different households but it includes only aggregated public capital and does not explicitly account for roads. They assume that public capital is provided by the rest of the world and enters directly the production function. This approach could be interpreted as a CGE-replication of the production function approach in the econometric literature. Both models will be described in detail below.

3 Theoretical background

As described above most of the literature states that improving the length and quality of roads and railroads would lead to higher growth and lower poverty. The reasoning behind this is a combination of different positive effects. Roads in general and paved roads in particular improve the connection between producers, markets and consumers. Enhancements of the roads and railroads of a country should hence lead to a more efficient allocation of goods and services.

This increased efficiency in the allocation is based on different channels:

1. As transport is easier and less costly producers have less losses on the road and spend less time for transportation i.e. the unit transport cost per marketed unit of the produced goods decreases. This should result in a higher share of produced products being marketed not only for the reason that less is lost on the way to the market but also because less of the production is consumed directly at the producers house.
2. As producers have an improved access to markets they are not relying on retailers but can directly access their potential consumers, this should increase competition on markets but also the possibilities for small producers to realize "fair" prices.
3. Consumers have better access to markets which increases the diversity of products available and reduces information asymmetries. Hence, this increases arbitrage between formerly separated markets.
4. As producers and consumers are linked more directly, production adapts more efficiently to demand as information flows are improved.

Olsson [2009] makes a distinction between direct and indirect effects from better roads. The first channel mentioned above represents the direct cost effect whereas the three other channels summarize the indirect effects. In addition Olsson [2009] expects that it is likely that the economy undergoes structural changes as technologies spread more easily across the country. All these effects should lead to a reduction in the trade and transport margin i.e. the difference between producer price and consumer price. This could either result in higher producer prices or in lower consumer prices. If producer prices rise this would lead to a higher share of marketed production and a lower share of home consumption leaving households with a higher income from marketing their production and the possibility to broaden the range of consumed products. A fall in consumer prices with constant producer prices enables consumers to increase their real consumption which has a clearly positive effect on welfare.

In addition to the aggregate effect which should be positive through a more efficient allocation of existing resources and a prevention of losses in goods and time from transportation an improvement in the road and railroad network will have a positive impact primarily on the rural population. The agricultural sector has the highest difference between producer and consumer prices so relative benefits for farmers should be highest. Moreover the rural population is typically spread across wide areas with a very limited access even to local or regional markets leaving this part of the population with limited consumption and income opportunities. Better roads should have additional welfare effects for the rural population also through improved access to health care and educational institutions.

In the production function literature infrastructure is normally treated as a production factor entering the national aggregate production function. In this paper we will model infrastructure as a means of transport. Infrastructure is used to transport the production to the market. The better the infrastructure the less capital and labour is required for transportation. Infrastructure enters the production function of the transportation sector and is a substitute for capital and labor in this sector but not in others. There exist large sectoral differences in transport intensities, hence, the higher the transport requirement of a specific good the more will this sector benefit from better roads.

4 Empirical relationship between infrastructure and transport costs

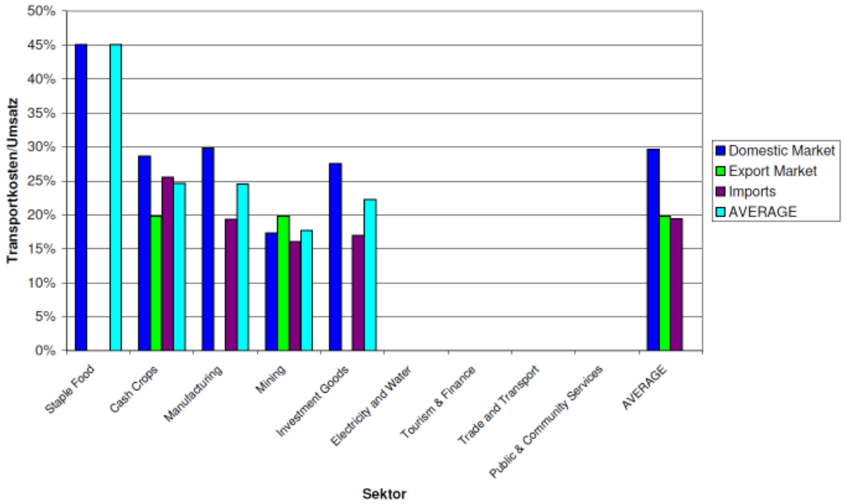
A crucial step in translating the theoretical considerations described above into a realistic CGE model will be to make an assumption on how much reduction in transport costs will result from an increase in the quantity and quality of roads. This relationship will be captured by a parameter that defines how much additional transportation will be made available from a specific amount of public capital in infrastructure. This parameter must be set exogenously.

Unfortunately the literature about the exactly quantified relation between increased expenditure on infrastructure and the effect on transport costs is rather vague: In a case study of several international transport corridors in Africa Teravaninthorn & Raballand [2009] find that an improvement of the roads from "fair" to "good" reduces the transport cost by approximately 15%. Unfortunately, they do not provide any quantitative information on the amount of public investment needed for this improvement. The vague classification "from fair to good" makes it difficult to integrate this estimation into a quantitative model. In contrast, studies using the production function approach provide concrete elasticities but these cannot be used in this paper as they measure the output effect, which is considered here as an indirect effect. In addition, these results differ significantly across studies. Estimations of tariff-equivalent costs of poor infrastructure in gravity models normally focus on *international* trade and the status quo of the transport network. They provide neither any estimates about *local* transport costs nor about concrete amounts of investment needed to provide a better road status.

Against this background this paper attempts to quantify the effect from better roads on transport costs directly. Given the fact that the CGE model uses Social Accounting data it has been decided to estimate the elasticity of the trade and transport margin with respect to the transport network from Social Accounting data, too. Social Accounting matrices are available for a large number of countries and provide detailed sectoral information on the demand for transport services. In a cross-sectional estimation for 58 countries from all over the world we investigate the effect of transport density on the trade and transport margin.

Figure 1 shows the sectoral trade and transport margin as a share of sectoral output for one country in the sample (Zambia) in order to give a general impression of the importance of trade and transport costs in developing countries.

Figure 1: The sectoral trade and transport margin in Zambia 2001



As dependent variable we use the sectoral spending on trade and transport services relative to sectoral output i.e. the trade and transport margin. We calculate this margin from input-output data both over all sectors (weighted) and only for agricultural sectors. Our main independent variable of interest is the transport network density measured here as the length of all railroads and paved roads in km per surface in km^2. In addition we control for *GDP per capita* as a proxy for the degree of development of the economy and hence for the stage of development of the markets, for the degree of urbanisation as a measure of dispersion of the market participants and for the size of the population.[1]

The data on trade and transport costs has been collected from input-output-tables from different sources, mainly the International Food Policy Research Institute (IFPRI) and the OECD. Data on road and rail road length as well as the control variables *GDP/capita* and *population* have been taken from a World Bank Dataset on infrastructure used by Fay & Yepes [2003][2]. Additional data has been taken from the Human Development In-

[1] A number of other control variables such as HDI, literacy, economic freedom and others have been tested but the results are not shown here as they are not qualitatively different and most variables have been insignificant.
[2] First published in: Canning [1998]. Available online at: `www.ce.cmu.edu/~hsm/im2004/lnotes/canning1.xls`

dex, Eurostat, the United Nations and national statistical authorities of the different countries.

The sample consists of 58 countries of which 28 are OECD countries, five East and South Asian countries, four eastern European and Middle-Asian countries, one middle East/North African country, nine Latin American countries and eleven countries from Sub-Sahara Africa. Five of these countries (Egypt, Russia, Bolivia, Belgium and Chile) have been excluded as outliers. The inclusion of these countries does not change the qualitative results but reduces the significance of most coefficients.[3]

Table 1 summarizes the results for different specifications. m_{ag} represents the trade and transport margin in the agricultural sectors, which should be more sensitive to bad roads compared to m_{all} which is the weighted average of the trade and transport margins in all sectors. *transp* is the transport network density, *urban* is the share of the population living in urban areas and *pop* is the size of the population, *gdp* stands for GDP per capita. All variables have been used in natural logarithms in order to reduce the differences in magnitude between the different variables as especially population size and GDP have much higher values than the rest of the variables.

Table 1: Results cross-sectional OLS regressions

Spec. no	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$	$ln(m_{all})$
# Obs.	53	53	53	53	45	45	45	45
ln(transp)	-0.16**	-0.18***	-0.19***	-0.12**	-0.14**	-0.16***	-0.04	-0.12**
ln(gdp)		-0.07	-0.05	-0.10		-0.07	-0.08	-0.10
ln(urban)			-0.08	-0.06			0.03	0.02
ln(pop)				-0.17***				-0.07
R^2	0.28	0.30	0.30	0.40	0.34	0.37	0.37	0.39
adj. R^2	0.27	0.27	0.25	0.35	0.33	0.34	0.32	0.33
F-test	20.1***	10.5***	6.9***	7.9***	22.2***	12.1***	7.9**	6.4***

*** significant at 1% level, ** significant at 5% level, * significant at 10% level

The regression clearly shows that an increased availability of roads and railroads significantly reduces the trade and transport margin. This effect is robust in a number of different specifications. The sign remains negative across the different estimations and the coefficient is insignificant in only one specification. These findings clearly confirm the theoretical reflections described above and show that the way of modeling infrastructure here is appropriate. The relation is confirmed not only for the agricultural sector but also for the weighted transport expenditure of all sectors.

[3]The results are robust with respect to the exclusion of particular observations, different sorting of the sample and an alternative specification of the transport network density (per capita instead of per surface).

The elasticities between 0.04 and 0.18 seem to be rather small but this is due to the fact that the independent variable is "transport density". As the transport density lies between 0.007 and 2.667 in our sample, a 1% increase of this density is often a very small shock. For Zambia for instance a 1% increase in the density would require 87 additional km of roads to be build and an amount of public investment of less than 0.01% of the GDP. This is far below the yearly public investment budget. In fact our results correspond quite well with the results of Teravaninthorn & Raballand [2009] if we assume that an improvement of the quality of roads from "fair" to "good" would approximately require a doubling of the transport density. This would imply a 15% decrease in average transport costs which is consistent with our elasticities.

As a robustness check we have tried to estimate subsamples for those countries where the transport margin was explicitly included in the dataset, which was only the case in IFPRI SAMs, but the sample is to small. The inclusion of additional or alternative controls like the HDI instead of GDP per Capita or an education index do not change the results qualitatively but provide results of lower reliability.

The results shown above are promising and support the general idea of this paper. Nonetheless, it is desirable to have even more reliable estimations of the elasticity. Ideally transport costs should include time and loss on the road. Unfortunately, the data for such an investigation is not available at a broad cross-sectional or panel level. It would be preferable to use "transport network capital" as explanatory variable, which would be closer to the theory and the concept of public investment. However, this could not be used due to data limitations, measurement problems and problems of comparability across countries. Moreover an extension of our sample by adding more countries would be good.

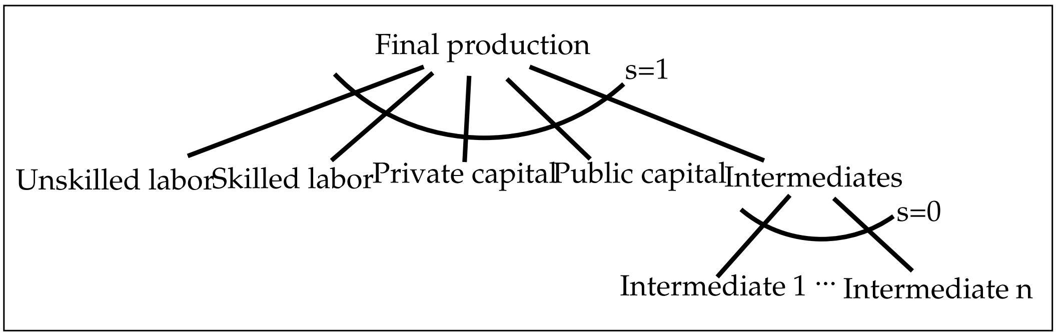
5 A Computable General Equilibrium model of road infrastructure

5.1 CGE models of infrastructure in the literature

The few CGE studies analyzing the effects of infrastructure investment are closely linked to the production function approach in the empirical literature. Public capital in infrastructure enters the production function and thus increases the production possibilities i.e. the total factor productivity.

In Adam & Bevan [2006] public capital is provided by the rest of the world and enters the sectoral (Cobb-Douglas-) production functions as a factor of production. The respective exponent has been taken from an empirical study by Hulten [1996] and reflects the public capital-elasticity of output. In this setup there exists a limited possibility to substitute between labor, capital and public capital. It is obvious that this aggregated approach does not capture the effects from transport networks explicitly, it summarizes the output effect of all different kinds of public investment. There are also no sectoral differences as the elasticity parameter is only available at the most aggregate level. Infrastructure in this model is just another factor of production with a particular provision (see figure 2).

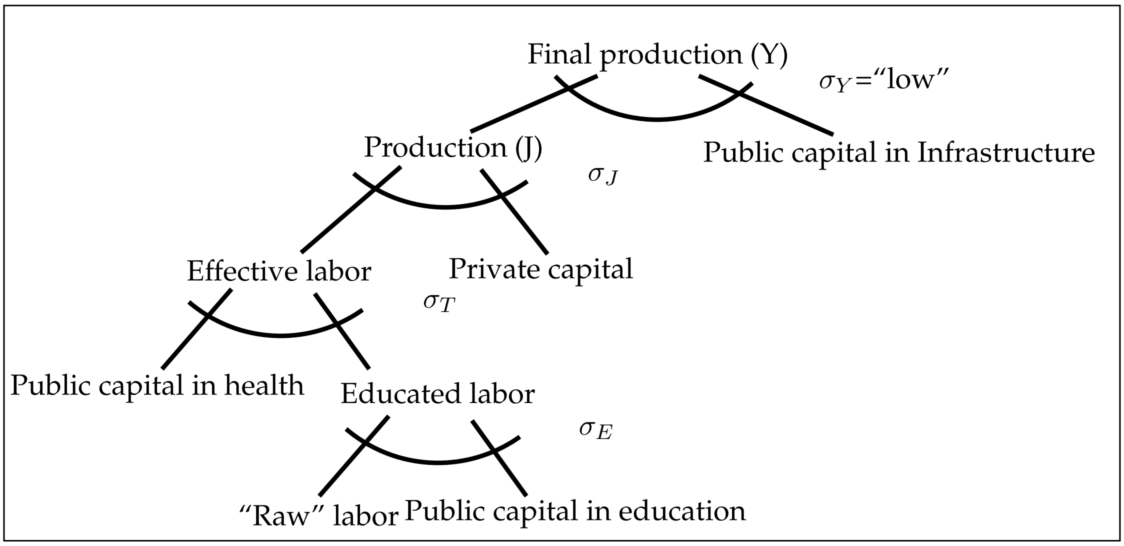
Figure 2: Production function in Adam and Bevan (2006)



Agenor *et al.* [2008] use a simulation model which includes three different forms of public capital into the national production function of a composite good: Public capital in health, education and infrastructure. These capital aggregates enter at different levels of a nested production function. Infrastructure enters in the top nest. Agenor *et al.* [2008] describe the elasticity of substitution between infrastructure and the labor/capital-nest to be “low”. While their model is very detailed concerning different forms of infrastructure it is limited with respect to the sectoral results. The model has only one sector of production and one representative household. Hence, there is no possibility to have different transport-intensities across sectors and different sectoral reactions to an increase in infrastructure (see figure 3).

Both models do not account for the fact that an important share of agricultural production in developing countries is directly consumed in the producer’s house. This part of agricultural consumption is not marketed and hence does not require transportation i.e. infrastructure. Both models do also not take into account that transport networks are of minor importance for production but are an essential requirement for market access. Hence better roads reduce the demand for capital and labor in transportation. These aspects are included in the model used in this paper. The production function we use in our approach clearly distinguishes between production and transportation to markets. It also accounts for sectoral differences in transport intensity and for home consumption. The general structure of production is shown in figure 4.

Figure 3: Production function in Agénor et al. (2008)



5.2 A stylized model of transport infrastructure

Before moving to a complex realistic CGE of infrastructure, we want to describe the way we integrated the above mentioned effects from transportation into a general equilibrium model in a small illustrative model which can be understood as an idealized version of the CGE model described later. The model is formulated as a mixed complementarity problem (MCP) which means that quantities are defined by zero-profit conditions and prices are defined by market-clearance conditions. If the zero profit conditions (equations (1) to (4)) hold as strict equations a positive quantity of the respective good is supplied and demanded. The market clearance conditions on the other hand determine the prices that ensure that supply equals demand. In addition to these an income-spending balance equation closes the model.

As infrastructure is crucial for market access we want to distinguish between production and marketing of goods. This is especially important as the assumption that all production is marketed will be relaxed later and some of the production will remain unmarketed. Marketing requires to transport goods which can be done by the aid of labour, capital and infrastructure. The less infrastructure available the more labour and capital must be used for transport. We assume that using infrastructure implies only operation and maintenance cost while using transport services means to pay for labour and capital.

In a closed economy with only one representative consumption good C, two factors of production and one representative agent, this could be modeled as follows: The composite good (X) is produced in a standard Cobb-Douglas production function. The zero profit condition for the good X is thus given by:

$$p_X = \left(p_L^{\alpha} \cdot p_K^{1-\alpha}\right) \tag{1}$$

The production X is then transported to the market using transportation services TS or a road. Both are combined in the transport aggregate T which is remunerated with the price p_T. This implies that the zero profit condition for C is defined as in equation (2). The subindex 0 indicates base year levels. Note that the transport aggregate T must always be provided in fixed proportion to the production X (see equation (4)). This does not imply that the demand for transportation services is fixed as transportation services and infrastructure are perfect substitutes. The supply of infrastructure is fixed exogenously and is hence not subject to a zero profit condition.

$$p_C = \left(p_X \cdot \frac{X_0}{C_0} + p_T \cdot \frac{T_0}{C_0}\right) \tag{2}$$

Transport services are produced by using capital and labor while transportation via a road only requires infrastructure capital $\overline{INF}$. Hence, the zero profit conditions for transport services and the transport aggregate are defined by equations (3) and (4) respectively.

$$p_{TS} = \left(p_L^{\beta} \cdot p_K^{1-\beta}\right) \tag{3}$$

$$T = \frac{T_0}{X_0} \cdot X \tag{4}$$

The respective prices of the commodities X and TS are defined by the market clearing conditions (5) and (6)

$$p_X \cdot X = \frac{X_0}{C_0} \cdot C \cdot \left(p_X \cdot \frac{X_0}{C_0} + p_T \cdot \frac{T_0}{C_0}\right) \tag{5}$$

$$p_{TS} \cdot TS = \frac{TS_0}{T_0} \cdot T \cdot \left(p_{TS}^{\frac{TS_0}{T_0}} \cdot p_{INF}^{\frac{\overline{INF}}{T_0}}\right) \tag{6}$$

The artificial price for the transport aggregate is defined by the market clearance condition for transportation, the shadow price for infrastructure by the respective condition for infrastructure.

$$p_T \cdot T = \frac{T_0}{C_0} \cdot C \cdot \left(p_X \cdot \frac{X_0}{C_0} + p_T \cdot T_0 C_0\right) \tag{7}$$

$$p_{INF} \cdot \overline{INF} = \frac{\overline{INF}}{T_0} \cdot T \cdot \left(p_{TS}^{\frac{TS_0}{T_0}} \cdot p_{INF}^{\frac{\overline{INF}}{T_0}}\right) \tag{8}$$

The prices for labor and capital result from the respective market clearing conditions (9) and (10)

$$p_L \cdot L = \alpha \cdot X \cdot p_X + \beta \cdot TS \cdot p_T \tag{9}$$

$$p_K \cdot K = (1-\alpha) \cdot X_0 \cdot X \cdot p_X + (1-\beta) \cdot TS_0 \cdot TS \cdot p_T \tag{10}$$

Total consumption equals total income, which is defined as the sum of income from labor, capital and infrastructure.

$$p_C \cdot C = Y \tag{11}$$

$$Y = L \cdot p_L + K \cdot p_K + \overline{INF} \cdot p_{INF} \tag{12}$$

The price equations or zero profit conditions equations (1) to (4) determine the quantities produced. If they hold there is positive supply and zero profit, the value of output equals the value of the respective inputs. The quantity equations or market clearance conditions equations (5) to (11) on the other hand determine the respective prices that ensure that supply equals demand for all goods. The last equation (12) ensures the income-spending-balance.

All other things being equal an increase in infrastructure would reduce the demand for TS. As infrastructure is a substitute for transport services. The reduced demand for TS frees up labour and capital that can be used for increased production.

A natural way to calibrate this model would be to assume that in the benchmark situation the existing stock of infrastructure ($\overline{INF}$) is zero. This assumption implies that - even though there might exist a stock of infrastructure - infrastructure in the benchmark is so low that it does not add to national welfare and that the existing trade and transport margin is an equilibrium outcome of the limited availability of roads. Investing in infrastructure would translate into a counterfactual with positive values of $\overline{INF}$ assuming that additional infrastructure allows a reduction of the spending on transport services (TS) and adds to overall welfare as it enters the national income Y.

The model represented by equations (1) to (12) has been calibrated to an artificial benchmark dataset with no infrastructure and $\frac{T_0}{X_0} = 0.1$ and increases in infrastructure by 1 to 10% of the GDP have been simulated. The following reactions result for the different variables of the model:

Variable	X	C	T	TS	p_X	p_C	p_T	p_{INF}	Y
Sign of effect $\partial x/\partial\overline{INF}$	+	+	+	-	-	-	-	-	+

These qualitative results are robust to changes in the benchmark data as well as in the assumed increase in infrastructure. The results from simulations in the idealized model show that the general ideas described below are correctly translated into a model. Nonetheless a number of extensions on the basic model are needed in order to draw a realistic picture of infrastructure investment. These are described in the next section.

5.3 Extensions to the small model

The model above does not take into account that roads are very likely to be provided publicly. This implies that there is no actual price for using the roads. The cost of roads must be divided into two categories: The investment cost that occurs before the road is in place and can be used and the maintenance cost; both must be accounted for as costs for the economy. It is very likely that the cost of road usage is far below the cost of transport services, nonetheless, the price for transportation services in the model reflects the alternative cost or shadow price for infrastructure. It may be interpreted as the welfare gain from increased infrastructure. This approach, to measure the gains from infrastructure by using the willingness to pay for roads, is for example used by Olsson [2009].

Related to the issue of calculating the correct price for transporting a good via a road is the fact that in the small model it is implicitly assumed that one additional unit of infrastructure investment provides exactly one additional unit of road which can only be used for a limited number of goods to be transported. It is obvious that this is not realistic at all. It will be assumed in the complex model that roads are public goods in the way that one additional kilometer of roads may be used to transport a large number of different goods. This is done by a multiplier on infrastructure.

An important feature of computable general equilibrium models is that one may implement heterogeneous households and different goods. This allows in a complex setup to assume different transport intensities across sectors. In addition it is very likely that welfare increases from better roads are especially beneficial for the rural population. This can be implemented in the model by assuming that the financing of roads is done via taxes proportional to the income of households but the benefits are assigned to households with respect to their location.

An important point for developing countries is the notion of subsistence agriculture or in general home consumption of household's own production. The decision to either sell their production on markets or directly use it at home will significantly depend on the costs a household would have to bear to transport their goods to the market and their purchases back home. Therefore the decision between home consumption and marketing of produced goods should explicitly modelled, this is done here, as shown in figure 4.

It is important to take into account that increased sales on markets increase the diversity of goods in the consumption bundle of the households. Nonetheless this is of less importance if the analysis is done on a rather high level of aggregation where goods have a very limited degree of substitutability.

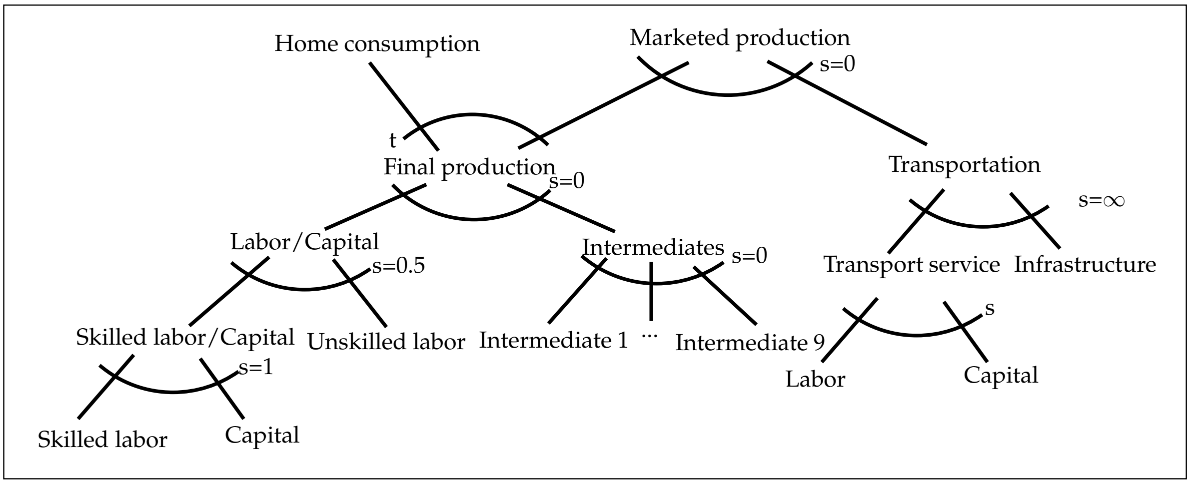
5.4 The Computable General Equilibrium model

The general idea shown in the small model above is translated into a disaggregated applied general equilibrium model. The model is structured as follows:

5.4.1 Production

Production is disaggregated into nine sectors, two of which are agricultural, four industrial and three are services. In each sector output is produced from a specific combination of intermediate inputs, capital, and two different types of labor. Labor and capital are assumed to be mobile across sectors. The production process is modeled using a nested production function as shown in figure 4.

Figure 4: Production function in this paper



Skilled labor and capital are imperfect substitutes in a Cobb-Douglas production function with a corresponding elasticity of substitution (s=1). We assume the substitutability between unskilled labor and skilled labor/capital to be more limited (s=0.5). Substitution between different intermediates or between intermediates and factors of production is ruled out by the assumption of a Leontief type top nest (s=0).

Domestic production may either be marketed or consumed at home. If it is marketed, it has to be combined with a transport good, which might either be the trade and transport margin (mg) or a road (which is initially not available and shown in grey color in figure 5 below). Domestic goods are imperfect substitutes for foreign goods. Domestically produced goods are combined with imported supply in a Constant Elasticity of Substitution (CES) function to form the Armington aggregate which is sold on domestic markets. Domestically produced goods may also be exported, but production of exports differs from production for local markets. This is implemented using a Constant Elasticity of Transformation (CET) function. The structure of the supply side is shown in figure 5.

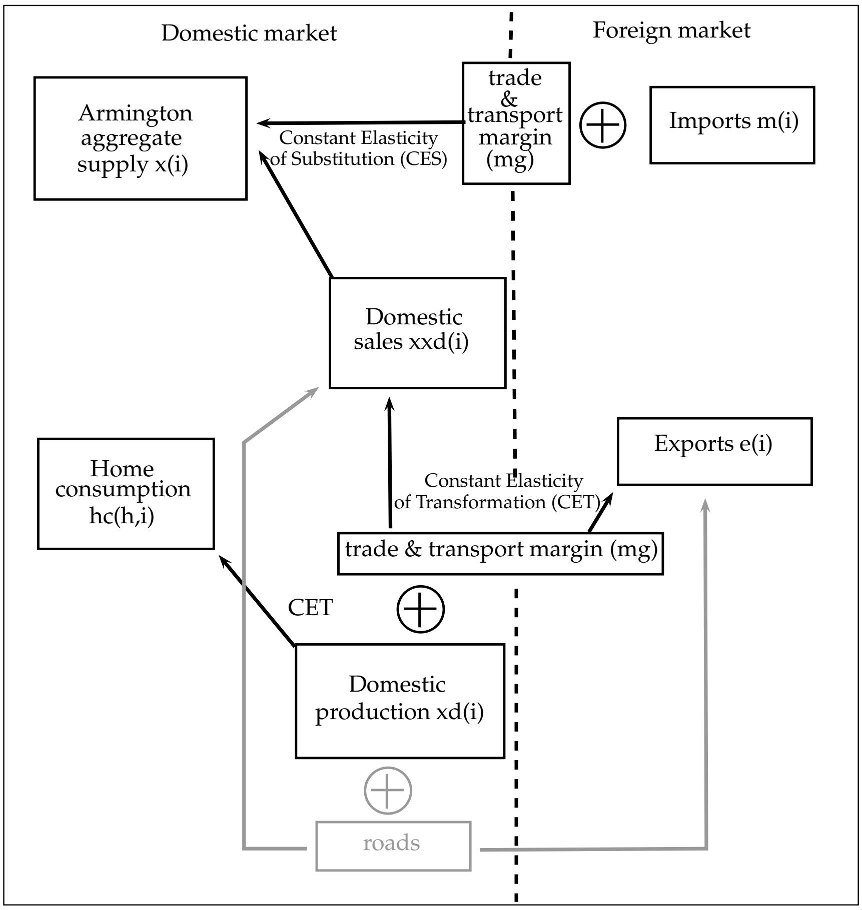


Figure 5: Supply side of the economy

5.4.2 Demand

Domestic demand consists of household demand, government consumption, investment and intermediate demand. Intermediate demand is linearly linked to the quantity of output. Household demand and government spending and investment are described below.

The model has two household types which differ in their location: an urban household and a rural one. In addition to the location the two household types differ in their factor endowment and their savings and direct tax rates. Households generate income from labor and capital. Apart from these income sources households receive transfers from the government. Income is used for tax payments, consumption and savings.

The government generates income from taxes, public capital and international aid. It spends its revenue on public consumption, transfers to households, interest payments to the rest of the world and public investment. Transfers, subsidies and interest payments are fixed exogenously. The only good the government buys are public services.

Savings are generated by households and the rest of the world. Savings are used for private capital investment. Total investment is always chosen to equal total savings. There exists only one investment good.

Infrastructure is introduced as an input to the production sector *road*. Infrastructure capital is combined with operation & maintenance to provide an alternative way of transporting goods to the market. The resulting *transport good* is a perfect substitute for the *trade and transport margin*. Nonetheless the supply of this alternative transport is limited by the supply of infrastructure capital. Transport via roads is remunerated with a shadow price that represents the welfare gains in terms of time savings and reduced losses. These gains are either assigned (i.e. transferred) to all households proportionately, only to rural households or to the government. This last case will be used as benchmark scenario. The government collects the welfare gains from better roads through taxes and uses these additional earnings to return the loans it took to finance the roads and to provide a higher level of public services and thus redistributes the welfare gains.

5.5 Calibration

The CGE model is calibrated to a base year data set in order to provide a benchmark structure of the economy and thus a point of reference. The data used for this paper is a slightly idealized Social Accounting Matrix (SAM) for Zambia. Zambia represents a typical Sub-Sahara African country here. Its transport network density of 0.01 km of road and railroad per km^2 of surface is among the lowest in the world and only at less than 1% of the German transport density. The SAM has been aggregated to a rather high level of aggregation: nine sectors of production, two households, two types of labour and one type of capital. Very low data entries have been removed from the data base as well as transfers between households and the different forms of indirect production taxes have been aggregated to only one. This aggregation and idealisation reflects the methodological focus of this study. In this manner it is ensured that effects from an increased road density are clearly identifiable and not ruled out by a very complex system of second and third round effects. Nonetheless the data set is rich in terms of the information provided concerning households' home consumption as well as the trade and transport margins. The data contains sectoral information about distinct trade and transport margins for domestic supply, imported supply and exports. It also provides sectoral levels of home consumption per household type. These information will be needed and used in the model.

The infrastructure-elasticity of the trade and transport margin that has been estimated empirically is reflected in the model in the input/output-relation of the road-sector which must be set exogenously. The results of the regression analysis described above have been used in the calibration process. The CGE model has been calibrated to an elasticity of 0.17 but different levels have been checked in robustness tests.

All other parameters for the calibration of the model are either calculated from the base year data (input coefficients, production function exponents, shares in consumption, tax rates, savings rates) or have been taken from the literature (CET- and CES-elasticities).

6 Simulations and results

6.1 Simulations

The CGE model described above has been used to run a series of simulations with increases in the transport density between 5% and 500%. It was decided to cover such a great range of shocks as we intend to investigate whether there might be a minimum amount of investment required to produce any effect and whether there exist decreasing returns to public investment. In addition public investment levels differ significantly across countries and thus there is no obvious counterfactual.

In order to provide a general idea of the dimension of the simulated shocks either projections about the infrastructure requirements of developing countries or past investment budgets of the respective states could be taken into account. As a point of reference one might consider the work by Fay & Yepes [2003] who calculated actual infrastructure investment needs for a large sample of countries for 2000-2010. In their paper they find that Sub-Saharan African countries should on average invest 5.5% of their GDP per year into infrastructure in general of which 2.8% new investments and 2.7% maintenance. Approximately 20% of these investments should be spent on roads. Very roughly calculated this would mean annual road investments of 1% of the GDP, half of which would provide new roads and half of which should be spent on maintaining old roads. Taking Zambia as an example this would mean a transport network budget of about 65 billion Zambian Kwacha (ZK). The Zambian public capital investment in the base year amounted to about 1000 billion ZK. Assuming that on average 20% of investment programmes are dedicated to infrastructure investment this would mean an investment budget of 200 billion ZK. Taking average investment costs for new roads as in Fay & Yepes [2003] these two figures would translate into an increase in the transport density between 60 and 200% not taking into account increases in the quality through maintenance.

It is obvious that these are only rough calculations to provide some idea of the dimension of the simulations. For this reason we demonstrate a wide range of shocks, keeping in mind that 5% is far below the requirements and 500% might be far above the optimal investment. The simulations mainly intend to show in which range the effects might be and to test whether there are decreasing returns at some point. Nonetheless it would be possible to investigate any given amount of investment or any given length of additionally paved roads.

In addition to the range of possible magnitudes of the public investment programmes one can think of different assumptions about the distribution of welfare effects. We therefore run the simulations for three different scenarios. In general welfare effects will be savings in terms of travelling time and goods loss. There is some empirical evidence for instance by Jacoby & Minten [2009] that these effects are the higher the more remote a household is located. In our setup with only two household types (rural and urban) this would mean that only the rural households profit directly from gains in their welfare. Alternatively one might argue that through a greater diversity of goods supplied and a general lowering in transportation costs urban households might benefit as well. Hence we also include a scenario where the welfare gains are assigned proportionally to all households. A third notion is the incorporation of the financing of an infrastructure project through increased taxes. In this scenario the government collects the welfare gains through some form of tax e.g. fuel taxes, road charges or motor vehicle taxes and uses the additional income to repay the loans it took to finance the road and to provide more and better public services. As this last scenario is distribution-neutral and will mainly show the supply side effects it serves as benchmark case in this study and is later compared with the other two cases.

It has been mentioned above that the dimension of the elasticity of transport costs with respect to the provision of roads has not been studied before. The only concrete number we have, stems from our own estimation. As a robustness check we therefore run a series of simulations where we keep the level of investment constant (at levels resulting to a 50% and 250% increase in the transport density) and increase the elasticity parameter. The results of these will be briefly summarised, too.

6.2 Results

The simulations show that with increasing availability of transport infrastructure, the demand for transport services decreases while the overall production and consumption increases. In the benchmark case where the government redistributes the welfare gains the increase in consumption is spread evenly across households.

Figure 6: Demand for transport services and average transport price

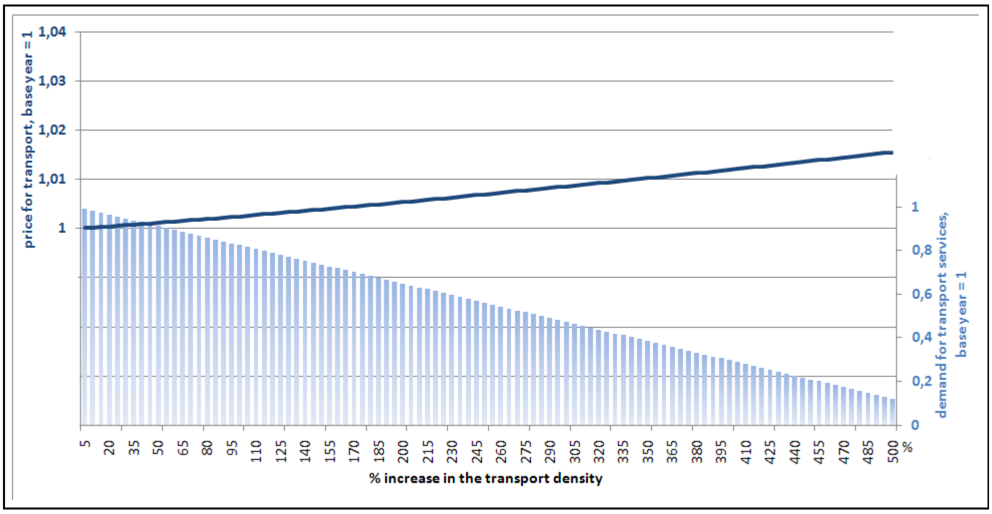
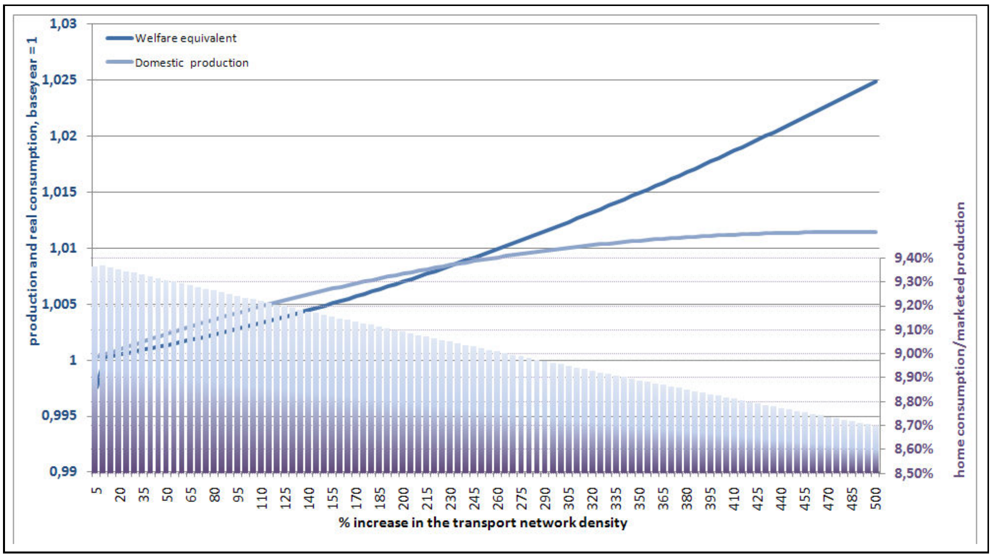


Figure 6 shows the demand for transport services and the aggregate transport price (aggregated over road transport and transport services) for given levels of infrastructure investment. The grey bars indicate that the demand for transport services clearly drops to nearly zero (−90%) for the largest increase in infrastructure. Nonetheless the price for transporting goods to markets slightly increases as the black line shows. This is due to the fact that the overall demand for both forms of transportation will increase given the increase in production. The effects on production and consumption are shown in figure 7.

Domestic marketed production (indicated by the dark line in figure 7) increases significantly (by app. 1% compared to the base year) with increasing availability of "free" transport. This is due to the fact that capital and labour that had been used in the transport sector before may now be used in other sectors. Concerning real output figure 7 reveals clearly decreasing returns from infrastructure as the line is concave. Home consumption relative to total output is captured in the grey bars and is clearly decreasing on the aggregate level.

The increased production is mainly consumed domestically. This can be seen in the light grey line which represents the Hicks equivalent change in welfare which is the change in real consumption possibilities of private households measured in units of initial con-

Figure 7: Production, Welfare and home consumption for different levels of infrastructure



sumption. The gains from better transport thus translate indeed into a higher level of overall welfare (up to +2.5% compared to the base year). Even though we see decreasing returns to investment, this is not the case for welfare. Here we see constant returns from infrastructure. The fact that the increased production is indeed a result of a higher real supply of factors for the other sectors is shown in figure 14 in the appendix. The aggregate use of factors of production in the other sectors expect transport services increases by up to +35% compared to the base year.

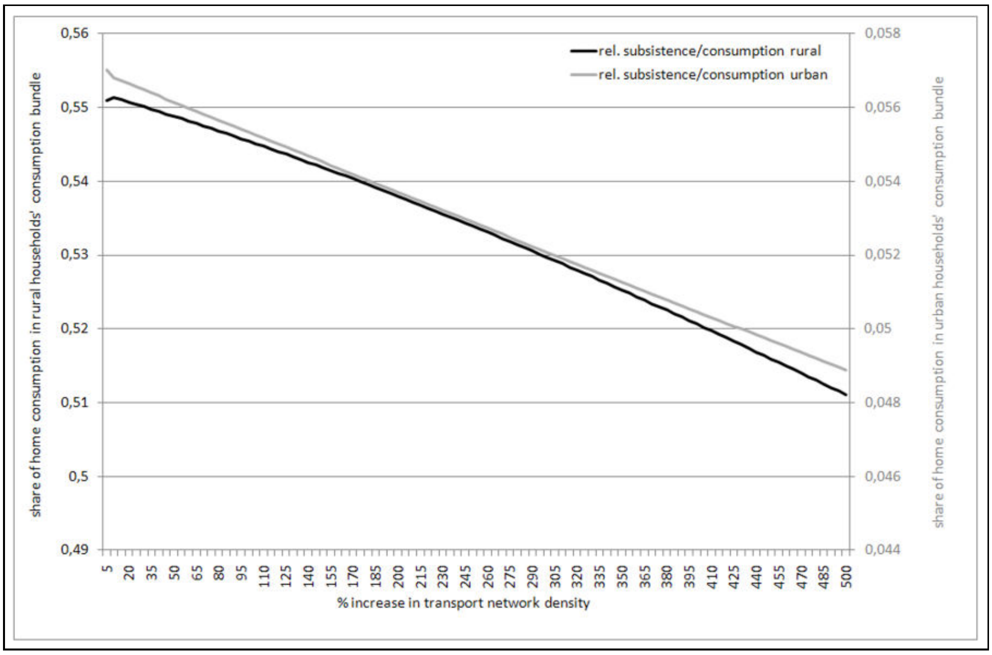
The additionally available factors are distributed very unproportionally across sectors. Figure 15 in the appendix shows the development of sectoral output relative to the benchmark.The production of trade and transport services clearly drops. Correspondingly we see a substantial increase in the production of public and community services by up to +150%. This effect has two reasons: First, the additional roads need maintenance which creates a higher demand for public services. Second, the government uses a part of its higher income to provide a higher level of public services (apart from road maintenance).

We see that home consumption evolves in complete correspondence to total sectoral production. This implies that in the sectors where home consumption is possible which are namely the agricultural sectors and food processing the share of home consumption is more or less kept constant and does not decline as theoretical reflections suggest. Nonetheless, as the production in other sectors increases significantly the share of home consumption in total consumption decreases (see 7). This apparent paradox can be explained as follows: Given the fact that agricultural products are assumed to be completely identical no matter whether they are purchased on markets or produced at home, home consumption is always preferable to marketed goods as long as there exist positive transport costs. Nevertheless, the welfare gains from better infrastructure allow the households to increase their consumption not only of the home consumed goods but also of other, market-only goods.

As the government collects the welfare gains in form of an endogenous tax on infrastructure in this baseline scenario, the investment programme is (nearly) distribution neutral. Figure 17 in the appendix shows the aggregated income effect for the two household groups and the relation of the per capita incomes of the two groups. The relation remains nearly unchanged.

Figure 8 illustrates the aforementioned phenomenon that even though the quantity of produced goods in the category of subsistence agriculture increases parallel to total output in agriculture, home consumption has a declining importance in the consumption bundles of both households.

Figure 8: Home consumption of the two household groups

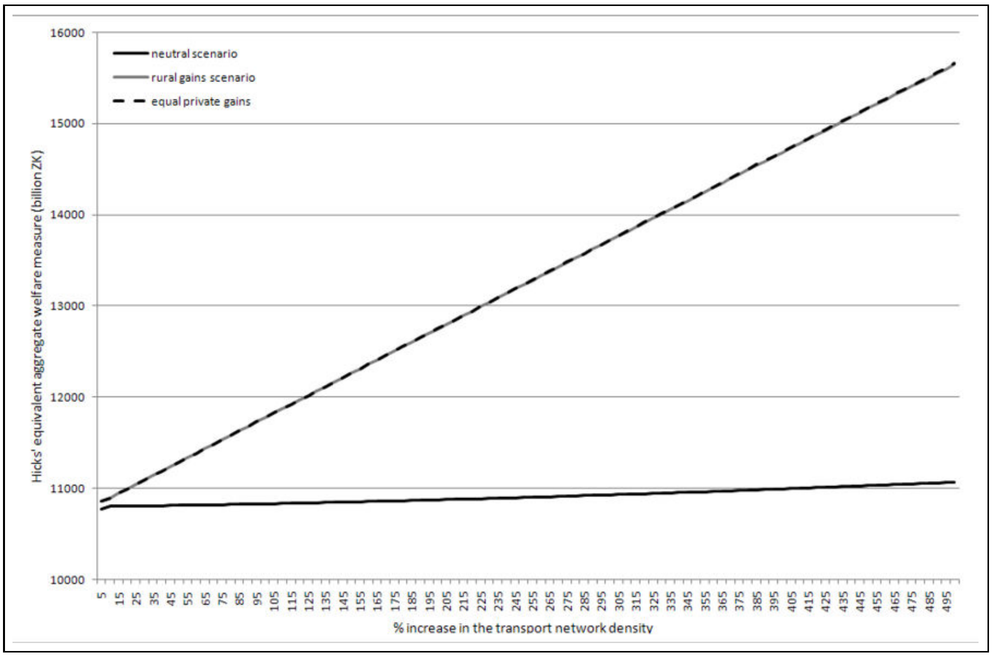


6.3 Alternative specifications of welfare effects

As described above welfare gains might either be assumed to favor the rural households, to be equally spread across all households or to be redistributed through public services. These three scenarios are simulated and compared.

On the aggregate level, the welfare effect depends significantly on the assumption which household receives the welfare gains directly. Figure 9 shows that the aggregate welfare

Figure 9: Hicks' equivalent welfare aggregate



effect is much higher if the welfare effects are completely assigned to the private sector. There exist differences with respect to the effect on transport prices as well. In figure 18 in the appendix it can be seen that if welfare effects are assigned to private households, no matter to which, there is virtually no effect on the price for transportation.

Figure 10 shows that the demand for transport services decreases slightly less severe if welfare effects are assigned to private households only. This is mainly due to the fact that private households demand goods which are more transport intensive compared to public services which are extensively demanded if the government collects the welfare gains and redistributes them through increased public service provision.

In contrast to the neutral scenario described in the previous section, the share of home consumption in total consumption rises with increasing supply of free transportation as can be seen in figure 11. The reason for home consumption gaining importance is mainly that private households demand mainly agricultural products and food. As these are partly produced at home, the share of subsistence agriculture in national production rises.

6.4 Robustness

The quantitative results of the simulations depend on the assumed elasticity of the trade and transport margin. As a robustness check we have held the level of investment constant at 50% and 250% increase in the transport density and changed the elasticity between 0.0004 and 0.013. At a rather low level of investment the results are only affected in their

Figure 10: Aggregate demand for transport services

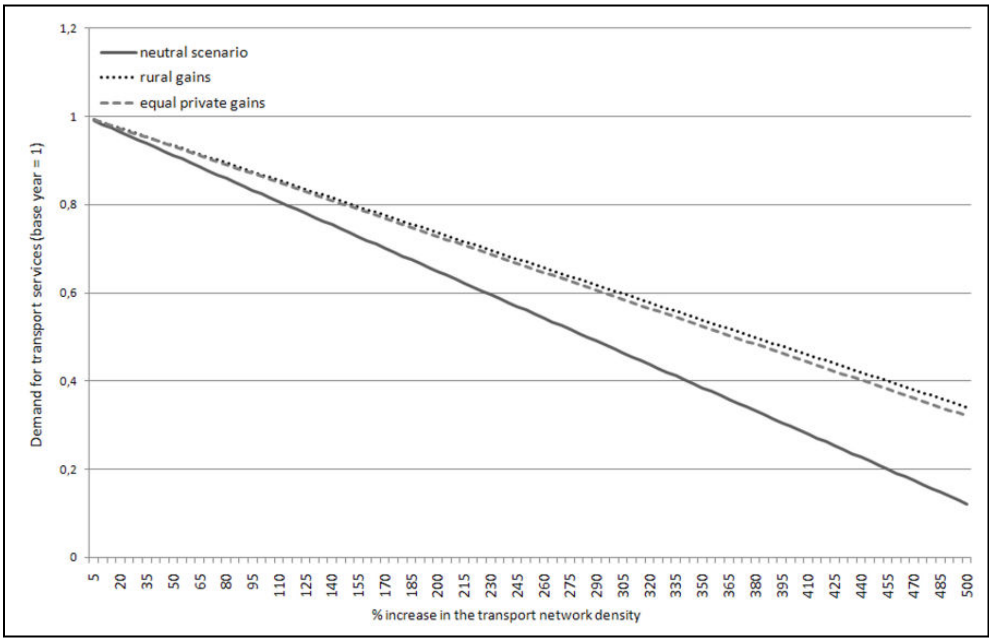
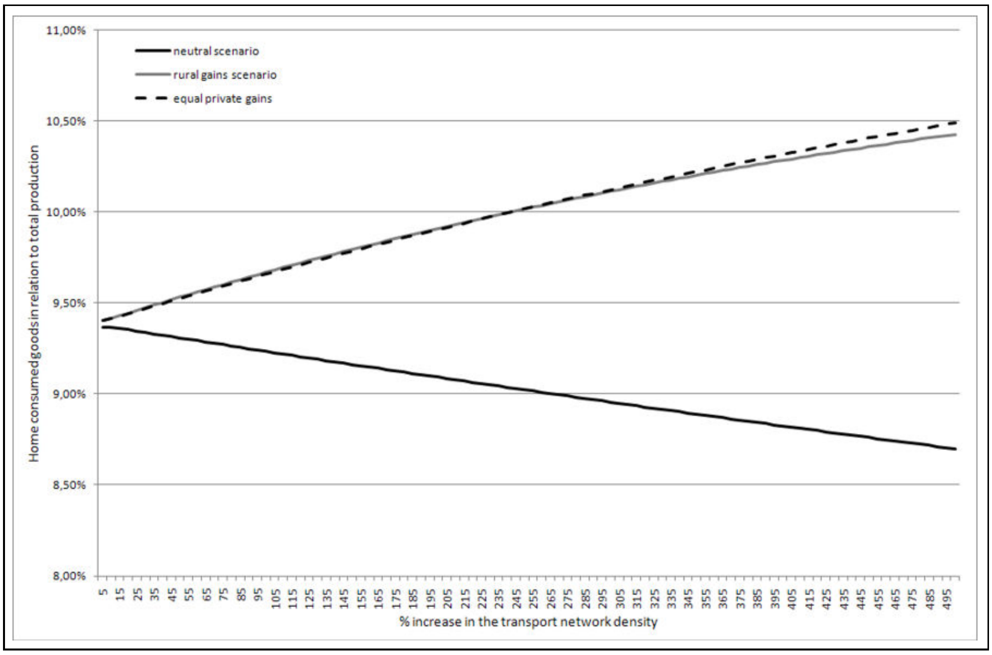


Figure 11: Aggregate level of home consumption



magnitude but show a linear relationship to the elasticity parameter. Nevertheless at rather high levels of investment we see a drop of the demand for transport services to zero up from an elasticity of 0.0035 and higher. In this case all other variables show a non-linear development as the price for transportation falls to a very low level at this point. The model should therefore only be applied with elasticities of the trade and transport margin between 0 and 0.003 and reasonable levels of investment. As an illustration we show here the development of the demand for transportation services and the development of domestic production only.

Figure 12: Aggregate demand for transport services

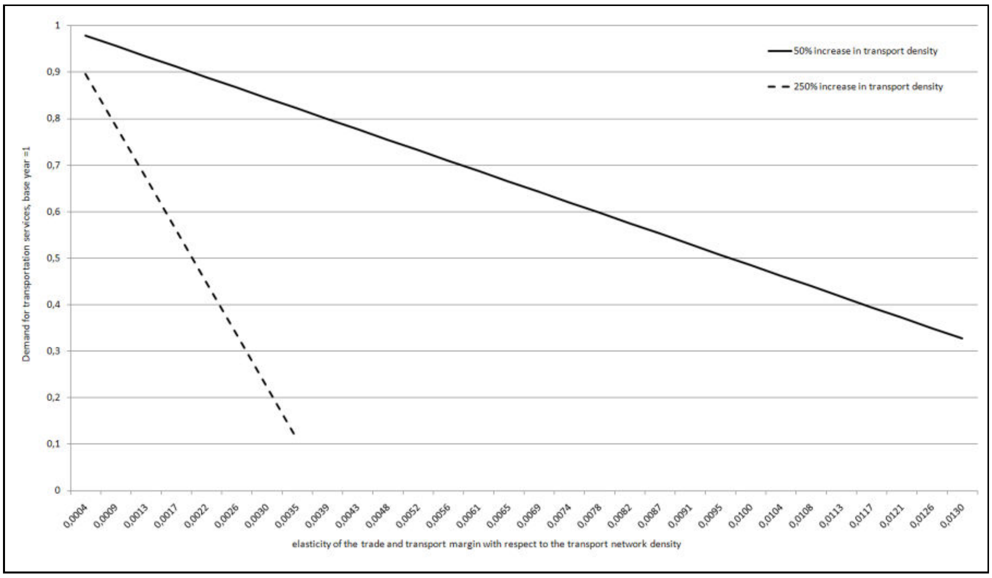
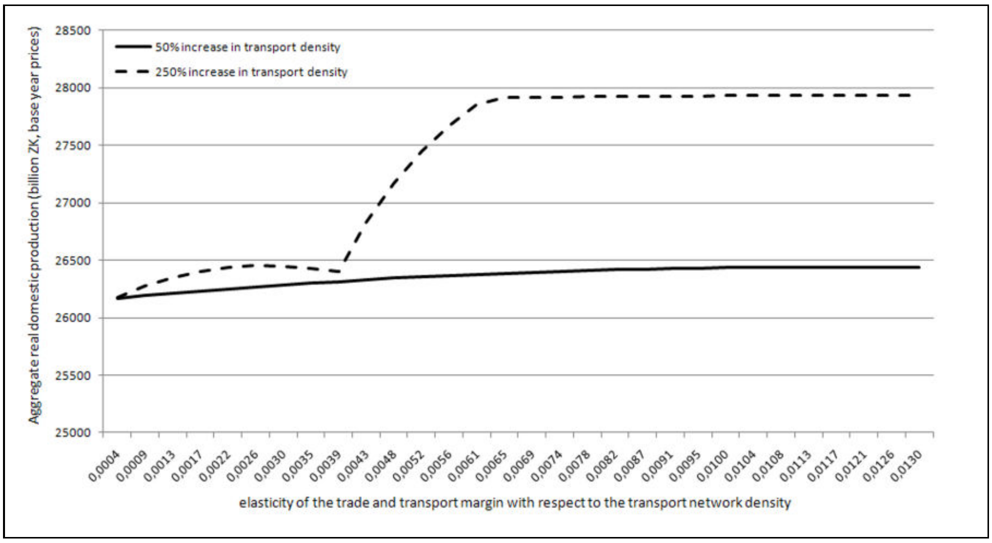


Figure 13: Aggregate domestic production



7 Conclusion

In this paper we have shown that even though there seems to be a consensus about the positive effects from better roads on development which is reflected in a number of investment programmes, the evidence in the development economics literature is mixed and far from being complete. Most importantly there is often no explicit accounting for different forms of infrastructure. In theoretical contributions it is often mentioned that there is a negative effect of roads on transport prices. Nonetheless, concrete quantitative results are scarce and unreliable.

This paper contributes to the existing literature on transport infrastructure in several ways. We show how the verbal theoretical reflections on the direct and indirect effects from better roads could be translated into a general equilibrium setup. We present a small stylized model of transport infrastructure and apply the same methodology in a complex CGE thereafter. In addition to this contribution in the field of modeling we present empirical evidence for a clear and significant negative relationship between transport networks and trade and transport margins. Our results are robust across a number of different specifications and the magnitude is comparable to the limited number of other results in related studies. We measure transport costs as the share of spending on trade and transport inputs in total sectoral output.

In simulations with the CGE model we confirm that with increasing availability of roads the demand for labour and capital for transport declines. These factors are used in the other sectors to produce a higher aggregate output. Welfare, measured as real consumption increases on average and at the disaggregate level for all households. The composition of the new consumption bundle and hence the reaction of subsistence agriculture depends on which households benefit directly from shorter traveling times and less losses on the road. As rural households spend a large share of their income on food the higher the rural gains the higher the share of agriculture in additional production and hence the higher the share of subsistence agriculture, too. We find decreasing returns to investment for output but not for welfare or poverty reduction. Especially if infrastructure programs are in favor of rural areas, the welfare effect is far above the output effect.

Even though the simulation results correspond to the theoretical predictions, the magnitude of the effects is relatively low compared with the high investment costs. This might be partly because of an underestimation of the elasticity of the trade and transport margin with respect to roads. We see in our robustness tests that altering the elasticity parameter significantly changes the magnitude of the effects. Moreover and probably more important, infrastructure investments induce a complex system of dynamic effects that have only been captured partly so far. The direct effect from increased investment has been neglected here as well as the possible dynamic effects induced by the structural changes shown here. A promising way of developing the model further would be to transform it into a fully dynamic model. However it would be important to have reliable estimations of the road-elasticity of the transport margin, too. Hence, an enlargement of the dataset for the empirical estimation is an important improvement of the current state of our research, too.

Despite the aforementioned limitations concerning parameter estimates and data, the model presented here can be very useful in evaluating concrete infrastructure investment projects and programs. It has been applied to a highly disaggregated dataset but could easily be used with very detailed data as well and thus provide important insights into distributional and sectoral effects from better transport networks, too.

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8 Appendix

8.1 Regression results

Table 2: Results cross-sectional OLS regressions. whole sample and explicit margins-Subsample

Spec. no	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Dependent	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$	$ln(m_{ag})$
# Obs.	58	58	58	58	16	16	16
ln(transp)	-0.14**	-0.07	-0.08	-0.04	-0.11	-0.08	0.11
ln(gdp)		-0.11	-0.04	-0.12		0.14	0.02
ln(urban)			-0.08	-0.06			0.40
ln(pop)				-0.2353***			
R^2	0.1085	0.1323	0.1402	0.2842	0.0120	0.1130	0.2271
adj. R^2	0.0926	0.1008	0.0924	0.2301	-0.0586	-0.0234	0.0338
F-test	6.8189**	4.1933**	2.9349**	5.2598***	0.1698	0.8282	1.1751

8.2 Simulation results

8.2.1 Benchmark case

Figure 14: Factor use in all sectors except transport

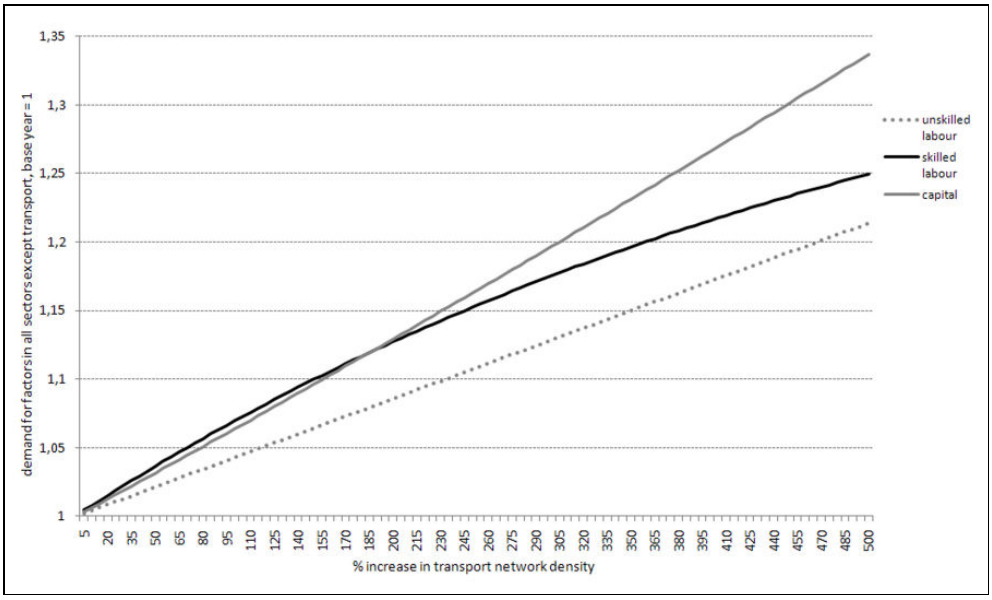


Figure 15: Sectoral output per sector

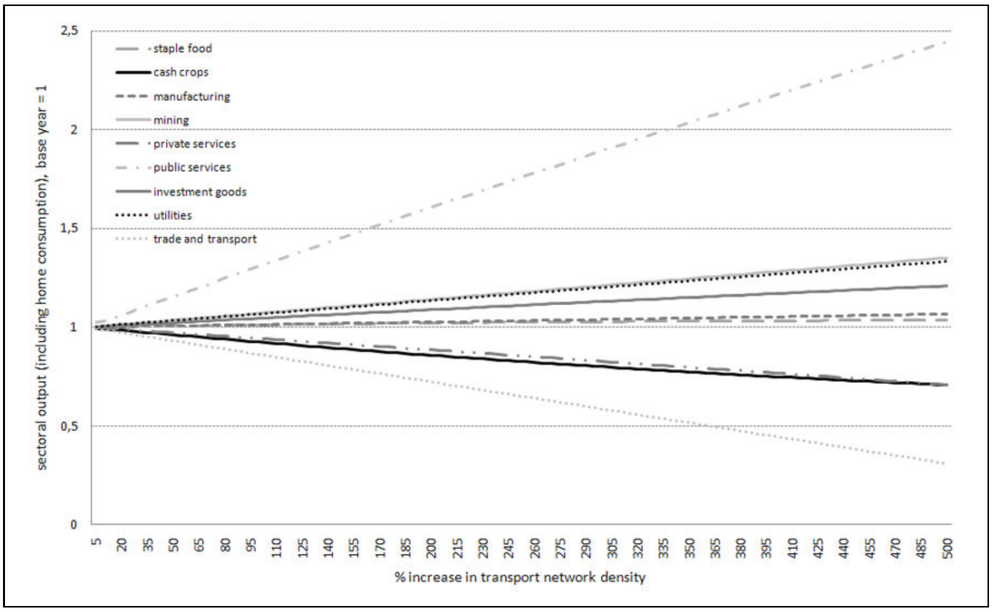


Figure 16: Home consumption in the different production sectors

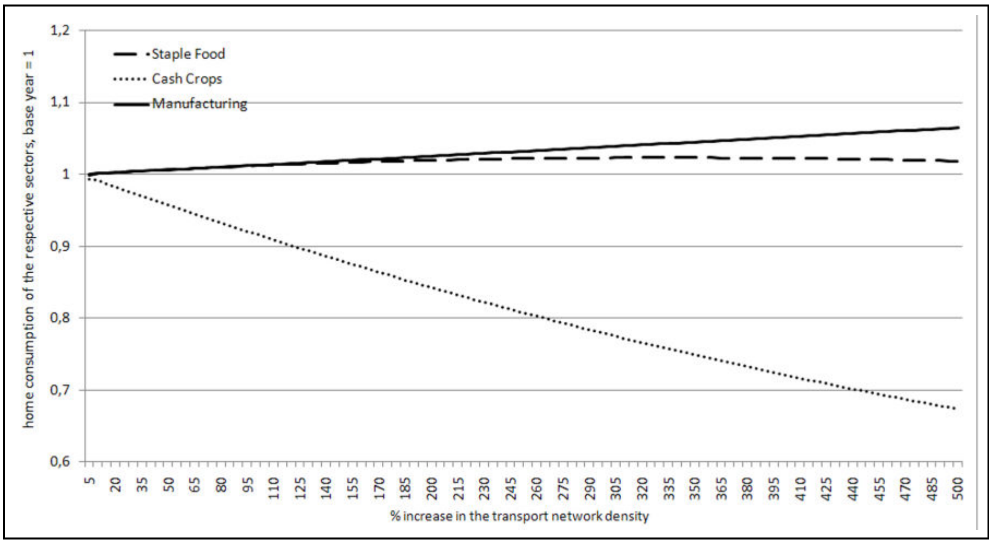
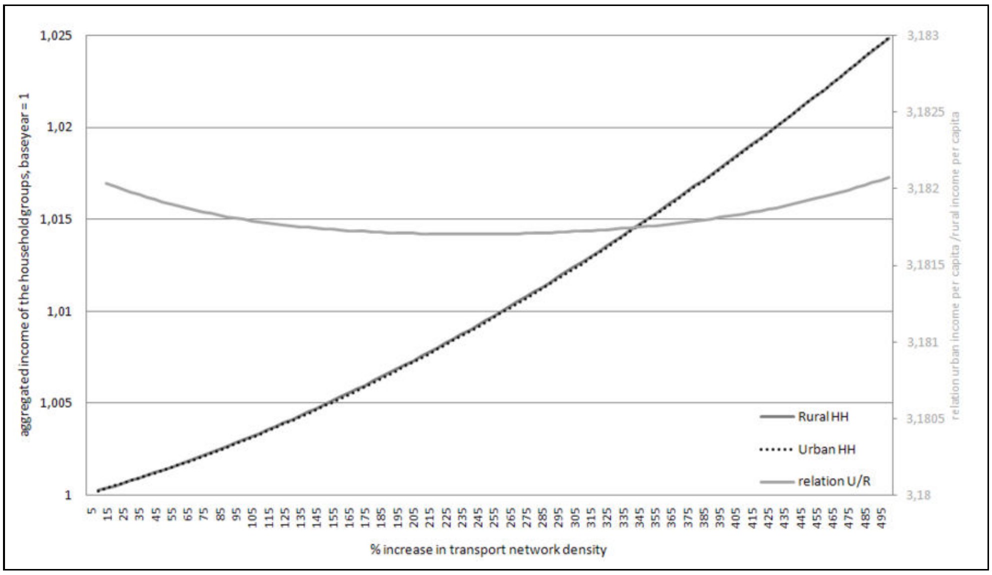


Figure 17: Households' Hicks equivalent change in welfare



8.2.2 Alternative welfare specifications

Figure 18: Aggregate price for transportation