Improving Africa's roads

Modeling infrastructure investment and its effect on sectoral production behaviour

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Abstract

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JEL Classification: O11, O55, R42

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

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Abstract

Investment in infrastructure is considered as a crucial instrument for economic development. Given the scarce resources for public investment in developing countries policy analysis should include a detailed perspective on the effects of infrastructure. This paper develops a modeling framework for the analysis of the effects of improved road infrastructure on the economy of African countries. The theoretical framework is tested empirically and used for simulations in a Computable General Equilibrium (CGE) model. The effects on production and welfare are analyzed. Additionally the model serves to investigate the effect of roads on the economic participation of rural households.

1. Introduction

Investment in infrastructure is considered as a crucial prerequisite for sustainable economic development. This common belief is reflected in a strong emphasis of 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. On average, Sub-Sahara Africa has a road density of only approximately 200 meters of paved roads per km^2 compared to 1400 meters in high income OECD countries.[1] Naude and Mathee [2007] state that: " It costs more to transport a vehicle from Abidjan to Addis Ababa than shipping the same vehicle from Abidjan to Japan." summarising the fact that especially intra-African and even intranational transport ways are extremely poor. The same

[1] Own calculations based on World Bank World Developing Indicators 2009.

applies to other forms of infrastructure such as electricity, sanitation and in-house water taps. [See Fay and Yepes, 2003]

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 total factor productivity and has a positive impact on long-term output. [See e.g. Gramlich, 1994; Romp and de Haan, 2007, for comprehensive surveys of the literature.] In the development economics literature several studies investigate the effects of infrastructure on national output using replications of Aschauer's approach. However, most studies on developing countries focus on poverty and income distribution instead of output, productivity or growth. [E.g. Calderon and Serven, 2008] Even though a number of project and case studies (esp. for industrial countries) find large positive effects from infrastructure on welfare and confirm reductions in transaction costs due to better transport ways [e.g. Wang, 2002], the macroeconomic infrastructure literature and more specifically the developing country literature in this field is very heterogeneous and fails to make clear predictions on the concrete macroeconomic effects.

This paper contributes to the existing literature by showing how transport infrastructure investment could be modeled in a general equilibrium setup with multiple sectors and heterogeneous households and by integrating the dimension of market participation of rural households into the analysis. This paper advances a disaggregated policy analysis on infrastructure investment in developing countries especially on the effects of rural roads in Africa.

We develop a stylized general equilibrium model which explicitly integrates transportation into the supply function of a representative good. In this model with two goods, a consumption good and a transport good, one representative agent and two factors of production, we show 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.

In an empirical cross-section analysis of the influence of transport network density on the trade and transport margin, we confirm that better transport networks reduce transport and transaction costs. Using cross-sectional data for 58 countries from all over the world and controlling for a number of country characteristics it is shown that a higher road length reduces the trade and transport margins.

We combine the stylized model and the estimation results 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. General equilibrium analysis provides a good toolkit to investigate the aggregate and disaggregate effects of infrastructure investment on a sectoral basis. 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 allows to investigate the effect of improved market access by means of better roads on the participation of rural households in the economy. The model allows for different assumptions concerning the allocation of the costs and benefits from infrastructure across the different household groups. It is shown that an increased 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 costs are crucial concerning the magnitude of these effects. This paper focuses on general modeling issues, but the model could easily be calibrated to other more disaggregated data and applied to specific investment programs.

Infrastructure in most African countries is at such a low level and many of these countries are so vast that even doubling the length of roads would leave the country with a very low network density. Bearing in mind the enormous investment costs for large scale infrastructure projects, our model results might provide guidance in cases where investment programs have to focus. From a sectoral production perspective, we find that especially those sectors with high tranport intensities and high capital intensity particularly benefit (mining, capital goods, utilities). Our distributional results show that the welfare distribution becomes more even if rural households are targeted specifically. Taking both into account, an agriculture-based development strategy would require an investment focus on rural roads whereas this is not necessary for resource-based development (like Zambia which is the example in this paper).

2. Overview of the relevant literature

2.1. Econometric studies on the infrastructure-development link

The literature on infrastructure impact is very heterogeneous in terms of what kind of infrastructure is analyzed and which outcome variable is considered. The following very brief summary of the relevant literature only includes the studies on the effects of transport infrastructure improvements in developing countries.

Most macroeconometric 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 labor, capital and technology but also on public capital. Public capital is normally measured using the perpetual inventory method. Most of the recent literature in this strand is based on Aschauer [1989] who applied the method to U.S. time series data. It has been applied to cross-section data including developing countries by Hulten [1996]; Ram [1996] and others. There seems to be a consensus on the positive effect from public capital on output even though the magnitude of this effect is disputed. Still, the methodology is only capable to investigate the effect of public capital as an entity instead of the effects of distinct forms (like roads) specifically. This is for example criticized by Calderon and Serven [2008]. Hulten and also Aschauer [2000] emphasize that not only the volume of infrastructure provided but also the efficiency of its use are important. Wu et al. [2010] find that government spending is less effective in low-income countries and attribute this to inferior institutions.

Estache [2006] reviews the macroeconometric literature on infrastructure and development 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 output effect the findings are positive. Concerning other aspects of development such as 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.[2] He underlines the specific importance of the subject for developing countries. The findings from cross-country studies concerning poverty and income distribution and its correlation with infrastructure suggest that the poor and rural population should be targeted specifically as they did not benefit from past infrastructure projects. [See Bryceson et al., 2008; Letiche, 2010]

In addition to the considerable macroeconomic literature numerous country and case studies evaluate specific projects or programs in developing countries. These studies mostly focus 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 and Ponce [2002] who compare three African countries, Fan et al. [1999] for India or Fan [2008] for Uganda. These studies

[2] A completely detached 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, the methodology does not provide insights on local transport. Examples are Yeats [1980], Limao and Venables [2001] and more recently Portugal-Perez and Wilson [2008].

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.

2.2. CGE models of infrastructure in the literature

In contrast to many 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 aggregate and sectoral output but also on income distribution, welfare and factor allocation as e.g. Stifel and Thorbecke [2003] emphasize. Furthermore, it allows to distinguish between direct and second round effects and it provides a clear counterfactual. Recent studies using this approach are Agenor et al. [2008] [applied to another country by Moreira and Bayraktar, 2008], Adam and Bevan [2006] and Levy [2006] as well as Jensen [2009].[3] These studies use quite substantially differing models: While Agenor et al. [2008]; Moreira and Bayraktar [2008] explicitly model all different forms of public capital and their effects, their model is very aggregated in terms of sectors and households. This model has only one representative household and only one aggregate good. The authors disaggregate the simulated macroeconomic effects from infrastructure using a dynamic microsimulation. Adam and Bevan's model, on the other hand, is 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 directly enters the production function. This approach could be interpreted as a CGE-replication of the production function approach in the econometric literature. A comparable approach is used by Levy [2006] who compares the effects of public investment either in the road infrastructure or in irrigation in Chad. She confirms that road investments after a windfall gain are capable to compensate Dutch Disease effects. However, her model applies an approach comparable to the production function approach and introduces infrastructure as a multiplier on total factor productivity. Hence it summarizes the effects from all public capital investments and does not specifically address the transport cost effect. Jensen [2009] explicitly refers to this caveat and adresses investments in road quality and road quantity by explicitly including a road network model based on the engineering literature. The economic

[3]These are only the studies for African countries given the focus of this paper. It would be ideal to use a spatial multiregional CGE model with Iceberg transport costs like e.g. Buckley [1992] and Haddad and Hewings [1999], unfortunately the regionally disaggregated data which is essential for this approach is not available for Sub-Sahara African countries.

part of his model is aggregated to a degree comparable with Adam and Bevan [2006] and Levy [2006] with five production sectors. Jensen [2009] includes the effect of roads on transport costs and welfare in a very detailed way. Unfortunately such a disaggregated analysis requires very detailed data which is not available for many African countries like the Chad (as in Levy's study) or Zambia (which is analyzed in this paper).[4]

All of these 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 production is not marketed and hence does not require transportation. The models by Agenor et al./Moreira/Bayraktar, Adam/Bevan and Levy 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. Our approach combines the disaggregated modeling of infrastructure as in Agenor et al. [2008] with the sectoral disaggreation as partly done in Levy [2006] and Adam and Bevan [2006] and additionally accounts for subsistence agriculture and O&M-costs. Our production function clearly distinguishes between production and transportation to markets as in Jensen [2009]. It also accounts for sectoral differences in transport intensity. The general structure of production is shown in figure 1.

3. Theoretical background

Most previous literature states that improving the length and quality of roads and railroads would lead to higher output 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 as e.g. Letiche [2010] points out: "[...] and when I asked them why they had not taken their surplus gain to market [...], they told me the roads were too potholed to make this feasible."

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[5]:

1. As transport is easier and less costly producers lose less of their production on the road and spend less time for transportation i.e. the unit transport cost per marketed unit of

[4] A detailed description of the models can be found in Appendix A.
[5] Based on the arguments by Olsson [2009].

the produced good decreases. This should result in a higher share of produced goods being marketed.

2. As producers have improved access to markets they are not relying on retailers but can directly access their potential consumers. This increases competition on markets.
3. Consumers have improved access to markets which increases the diversity of products available for consumption 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.

In addition, Olsson [2009] expects that the economy undergoes structural changes as technologies spread more easily across the country. All these effects should lead to a reduction in the spread between producer and consumer price. 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 reduction in consumer prices enables consumers to increase their real consumption which has a clearly positive effect on welfare.

In addition to the aggregate positive effect an improvement in the road and railroad network will have a positive impact primarily on the rural population. The rural population is typically spread across wide areas with very limited access even to local or regional markets leaving this part of the population with limited consumption and income opportunities. In addition, better roads improve the access to health care and educational institutions for the rural population.

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 more directly as a means of transport. There exist large sectoral differences in transport intensities, hence, higher transport requirements of a specific good induce higher benefits from better roads for this sector.

4. A Computable General Equilibrium model of road infrastructure

4.1. A stylized model including transport infrastructure

Before moving to a more realistic CGE of infrastructure, we illustrate in a small stylized model how the above mentioned effects from transportation are integrated in a general equilibrium model. The model is formulated as a mixed complementarity problem (MCP) which means that quantities are associated with zero-profit conditions and prices are linked with market-clearance conditions.[6] If the zero profit conditions (equations (1) to (4)) hold as strict equalities a positive quantity of the respective good is supplied and demanded. The market clearance conditions (equations (5) to (10)) determine the prices that ensure that supply equals demand. An income-spending balance equation (11) closes the model.

We distinguish between the production and marketing of goods. This is important as the assumption that all production is marketed will later be relaxed and some production will remain unmarketed. Marketing requires the transport of goods by means of labor, capital and infrastructure. Poor infrastructure leads to a higher need of labor and capital used for transport. We assume that using infrastructure implies only O&M cost while using transport services means to pay for labor and capital.

We model a simple closed economy with only one representative consumption good C, two factors of production and one representative agent: The composite good (X) is produced in a standard Cobb-Douglas production function. The zero profit condition for X is given by:

$$p_X = p_L^{\alpha} \cdot p_K^{1-\alpha} \tag{1}$$

where p_X is the price for one unit of X, p_L the wage and p_K the capital rent with α and $(1-\alpha)$ being the input coefficients of labor and capital, respectively.

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. The transport aggregate T is assumed to be provided in fixed proportion to the production of X. The zero profit condition for C is defined as in equation (2).

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

[6] See Rutherford [1999] for a detailed description of the approach and appendices 1&2 in Markusen [2004] for an illustrative application.

p_C being the consumption price and p_T being the unit transport cost. Prices are multiplied with the relation of production to consumption and transportation to consumption in the base year. The subindex 0 indicates base year levels. This does not imply that the demand for transportation services (TS) is fixed as transportation services and infrastructure are substitutes. The supply of infrastructure is fixed exogenously and is hence not subject to a zero profit condition.

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

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

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

The respective prices of the commodities X and TS are complementary to 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 value of the production of X and TS respectively (left hand side of equations (5) and (6)) must equal the value of demand of the respective good, given by the right hand side of the equations. The price adjusts to fulfill this condition. Both are scaled to base year levels for reasons of simplicity.

The artificial price for the transport aggregate (p_T) is defined by the market clearance condition for transportation, the shadow price for infrastructure (p_{INF}) by the respective condition for infrastructure.

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

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

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

$$p_L \cdot L = \alpha \cdot X_0 \cdot X \cdot p_X + \beta \cdot TS_0 \cdot TS \cdot p_T \tag{9}$$

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

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

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

$$Y = L \cdot p_L + K \cdot p_K + \overline{INF} \cdot p_{INF} \tag{11b}$$

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 labor and capital that can be used for increased production.

A natural way to calibrate this model is 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 poor 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 for a reduction of spending on transport services (TS) and adds to overall welfare as it enters the national income Y.

The model represented by equations (1) to (11b) 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 GDP have been simulated. The following reactions to an increase in $\overline{INF}$ result for the different variables of the model:[7]

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

Table 1: Simulation results - stylized model

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 above are correctly translated into a model. Nonetheless, several extensions to the basic model are needed in order to draw a realistic picture of the effects of infrastructure investment and to allow for policy impact assessments. These are described in the next section.

[7]Results for p_L and p_K depend on the assumed factor intensities and are not shown here. P_K served as numéraire in this example.

4.2. Extensions to the small model

An important feature of CGE models is that one may integrate heterogeneous households and different goods. This allows for different transport intensities across sectors. In addition it is very likely that welfare increases from better roads are particularly 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 households' income but the benefits are assigned to households with respect to their location.

An important issue for developing countries is the notion of subsistence agriculture or in general home consumption of households' 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 be modeled explicitly. This is done here, as shown in figure 1.

4.3. The Computable General Equilibrium model

The general idea shown in the small model above is translated into a disaggregated CGE model.[8] The model is structured as follows:

4.3.1. 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 1.

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). The supply of labor, capital and land is fixed exogenously to base-year levels.

[8] The general structure of model presented here is comparable to other developing country CGEs like e.g. the IFPRI model. The model has been programmed using MPSGE and solved using the GAMS/PATH solver. A copy of the model code can be made available on request.

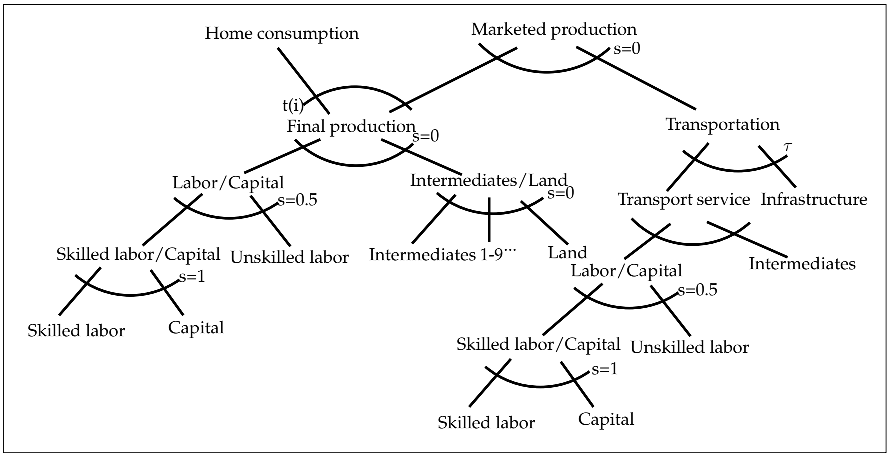

Figure 1: Nested production function

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 trade and transport services (mg) or a road. The choice between *home consumption* and marketed production is determined by a constant elasticity of transformation (CET) function. Home consumption is only possible in agricultural sectors and basic manufacturing. 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.[9]

Infrastructure serves as an input in the production sector *road*. Infrastructure capital is combined with O&M, which is paid for by the government, 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 savings in time, capital and goods. This approach of measuring the welfare gain from infrastructure by the willingness to pay for roads is used in Olsson [2009] and adopted here. These gains are either assigned (i.e. transferred) to all households proportionately, only to rural households or to the government.

4.3.2. Demand

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

[9]The Armington elasticities have been taken from the literature. See the appendix for details.

The model has two household types which differ in their location: urban and rural. The two household types also differ in their factor endowments, their savings, direct tax rates and consumption preferences. Households generate income from labor and capital. Apart from these income sources households receive transfers from the government. Household 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, public investment and operation and maintenance of roads. Transfers, subsidies and interest payments are fixed exogenously. The only good the government buys apart from the public investment good are public services. In the benchmark scenario the government collects the welfare gains from better roads through endogenous taxes and uses these additional earnings to provide a higher level of public services or transfer payments and thus redistributes the welfare gains.

Savings are generated by households and the rest of the world. Savings are used for private capital investment. The model is closed by total investment that always equals total savings. Infrastructure capital is provided from an external source, international aid. The external balance is fixed over different scenarios. The factor markets are closed by flexible prices and factor mobility.

5. Empirical relationship between infrastructure and transport costs

Translating the theoretical framework into a suitable CGE model requires information on how much reduction in transport costs will result from an increase in the quantity and quality of roads. The literature is rather vague about the exactly quantified relation between increased expenditure on infrastructure and transport costs: In a case study of several international transport corridors in Africa Teravaninthorn and 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. Estimations of tariff-equivalent costs of poor infrastructure in gravity models focus on *international* trade. They provide neither any estimates about *intranational* 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. As the CGE model uses Social Accounting data it is natural to estimate the elasticity of the trade and transport margin with respect to the transport network from Social Accounting data, too. In a cross-sectional estimation for 58 countries from all over the world (28 high income, 22 middle and 8 low income countries) we investigate the effect of transport density on the trade and transport margin. This is a straight forward way to test the aforementioned theoretical reflections and the model setup empirically and provides us with a concrete parameter estimate for future policy analysis in the CGE model.

We estimate the following equation:

$$ln\, m_i = \alpha + \beta\, ln\; transport_i + \gamma_1 ln\; gdpc_i + \gamma_2 ln\; urban_i + \gamma_3 ln\; pop_i + u_i$$

As dependent variable we use sectoral spending on trade and transport services relative to sectoral output, i.e. the trade and transport margin (m_i). We calculate this output-weighted margin from input-output data both over all sectors and only for agricultural sectors. Our main independent variable of interest, the transport network density ($transport_i$), is 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* ($gdpc_i$) as a proxy for development of the economy and hence for the stage of market development, for the degree of urbanization ($urban_i$) as a measure of dispersion of market participants and for the size of the population (pop_i).[10]

The data on trade and transport margins comes 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* are taken from the World Development Indicators (WDI) Database for more recent years. Missing data has been taken from the Human Development Index, Eurostat, the United Nations and national statistical authorities of the different countries.[11]

Table 2 summarizes the regression results for different specifications. m_{ag} represents the trade and transport margin in the agricultural sectors, which should be more sensitive to road quality compared to m_{all} which is the weighted average of the trade and transport margins in all sectors. All variables have been used in natural logarithms such that the results can be interpreted as elasticities.

[10]Several other control variables such as the Human Development Index (HDI), literacy, economic freedom, surface and others have been tested but the results are not shown here as they are not qualitatively different and most variables have been insignificant.

[11]Table B.3 in Appendix B shows the descriptive statistics for the sample.

Table 2: Results of 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 regressions clearly show that an increased availability of roads and railroads significantly reduces the trade and transport margin. This effect is robust across different specifications. The sign remains negative in all estimations and the coefficient is insignificant in only one specification. These findings clearly confirm the theoretical considerations described above and support our way of modeling infrastructure. The relation is confirmed not only for the agricultural sector but also for the weighted transport expenditure of all sectors.[12]

In fact our results correspond quite well with those of Teravaninthorn and Raballand [2009] if we assume that an improvement of the quality of roads from "fair" to "good" approximately requires a doubling of the transport density. This would imply a 15% decrease in average transport costs which is consistent with our elasticities.

The empirical results show that infrastructure investment programs are capable (if they are efficient in providing additional roads) to reduce transport costs significantly. However, for countries with a very low starting point like many African countries, the required investment to reach a significant and large cost effect would be enormous. Policy makers who plan large scale infrastructure programs should bear in mind that the effect is slightly larger and more robust in agricultural sectors. Hence, infrastructure programs have the potential to support agriculture-oriented development strategies in particular.

6. Simulations and results

6.1. Calibration

The CGE model is calibrated to a base year data set in order to provide a benchmark structure of the economy. The data used for this paper is a slightly idealized SAM for Zambia.

[12]The inclusion of additional or alternative controls like the HDI instead of GDP per capita or an education index does not change the results qualitatively but provide results of lower reliability.

Zambia represents a typical Sub-Sahara African country here. Its transport network density of 0.012 km of paved roads and railroad per km^2 of surface is among the lowest in the world. The SAM has been aggregated to a rather high level of aggregation: nine sectors of production, two households, two types of labor and one type of capital. For simplicity, very small data entries have been removed from the data base and transfers between households, too. This aggregation 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 hidden in a very complex system of indirect effects. The data set is rich in terms of the information provided on 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. Information of this type is needed for a consistent calibration of the model.[13] The previously estimated infrastructure-elasticity of the trade and transport margin is reflected in the model in the input/output-relation of the road-sector which must be set exogenously.[14]

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 relevant literature (CET- and CES-elasticities in the Armington formulation).

6.2. Simulations

The CGE model described above has been used to run a series of simulations with increases in the transport density between 5% and 100%. This large range of shocks serves 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 at this stage of model development. Note, a 100% increase in infrastructure density is comparable to the infrastructure shock of 2.5% of the GDP simulated by Adam and Bevan [2006]. Agenor et al. [2008] and Levy [2006] simulate substantially larger infrastructure shocks of 5% and 15% of the GDP respectively.

In addition to the range of possible magnitudes of the public investment programmes one

[13]The original dataset is: Thurlow et al. [2005]. A copy of the aggregated SAM is available on request.

[14]The CGE model has been calibrated to an elasticity of 0.15 but different levels have been implemented in robustness tests.

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 traveling time, capital in transportation and avoidance of goods loss. In our benchmark scenario the government collects the welfare gains through taxes (e.g. fuel taxes, road charges or motor vehicle taxes) and uses the additional income to redeem the loans it took to finance the road and to provide more and better public services. As this scenario is distribution-neutral and will mainly show the supply side effects it serves as a benchmark case and is later compared with the other two cases. There is some empirical evidence for instance by Jacoby and Minten [2009] that welfare gains are higher for households which are located in remote regions. In our setup with only two household types (rural and urban) this would mean that only the rural households benefit directly from welfare gains. Alternatively, urban households might benefit as well with a greater diversity of goods supplied and a general lowering in transportation costs. Hence we also include a scenario in which the welfare gains are assigned proportionally to all households and one where all welfare gains are assigned to the rural household only.

6.3. Results

The simulations show that with increasing availability of transport infrastructure, the demand for trade and transport services (and thus for capital and labor in transportation) 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.[15]

The demand for transport services clearly decreases with increasing availability of roads. Nevertheless, the price for transporting goods to markets remains constant. This is due to the fact that the overall demand for the transport aggregate will increase given the increase in production. The effects on production and consumption are shown in figure 2.

Domestic marketed production (indicated by the black line in figure 2) increases with increasing availability of "free" transport.[16] Capital and labor released in the transport sector may now be used in other sectors. Home consumption relative to total output is captured in the grey bars and is clearly decreasing on the aggregate level.

[15] We only present selected results in form of figures here, a complete results listing is in Appendix D.

[16] The increase in domestic production by only about 0.25% seems to be a small reaction to an increase in infrastructure by 100%. However, a doubling of infrastructure would lead to an infrastructure density of 0.024 km per km^2 of surface which still is one of the lowest infrastructure densities in the world. Nonetheless, it would require to build about 7000 km of new roads and rail roads which would be an expensive project for the Zambian government. Zambian infrastructure is so far below the requirements that even doubling it would still have only small effects.

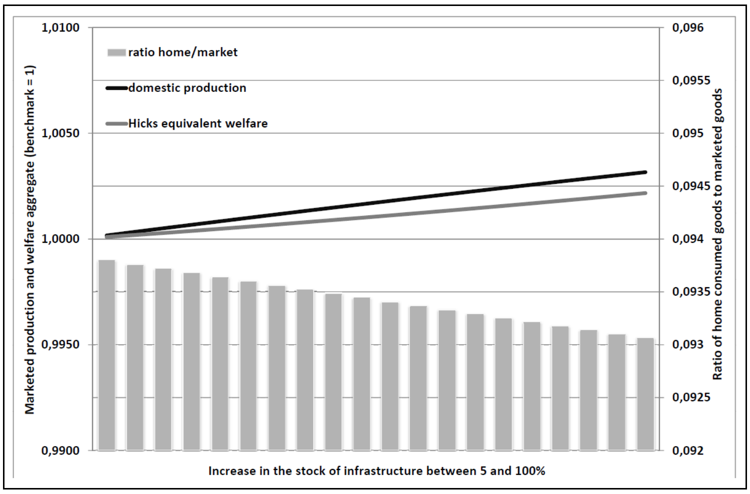

Figure 2: Production, Welfare and Home Consumption for different levels of infrastructure

The increased production is mainly consumed domestically. The grey line represents the Hicks equivalent change in welfare which is the change in real consumption possibilities of private households measured in units of initial consumption. The gains from better transport thus translate indeed into a higher level of overall welfare. The aggregate use of factors of production in the other sectors except transport services increases compared to the base year.

The additionally available factors are distributed very unevenly across sectors. The production of trade and transport services clearly drops. Correspondingly, we see a substantial increase in the production of public and community services. This effect has two sources: 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).

As the different sectors have differing transport intensities a shock on transport costs will have substantially different effects on the different sectors. Indeed we see in figure 3 that sectoral production in some sectors substantially increases whereas other sectors are nearly unaffected. Namely public and community services directly benefit from increased demand due to road maintenance and from additional tax income. But also the mining sector (MIN), the utilities sector (EAW) and the capital goods sector (INV) benefit from lower transportation costs and additional capital and labor supply. Staple food (STF) and other manunfacturing (MAN) are nearly unaffected whereas agricultural cash crops production (CCR) and tourism and financial services (TFI) face shrinking production.

The mining and capital goods benefit because they are caracterized by a combination of high transport intensity and high capital share in value added. The prices both for transport and capital decrease and thus these sectors benefit twice. Public and community services benefit from a positive demand shock. Electricity and water are also capital intensive and thus benefit from decreasing costs. Relative wages on the other hand rise and thus the labor intensive sectors staple food and cash crops do not benefit. Transport services face a negative demand shock as well as financial services which are the main intermediate demanded in transport.

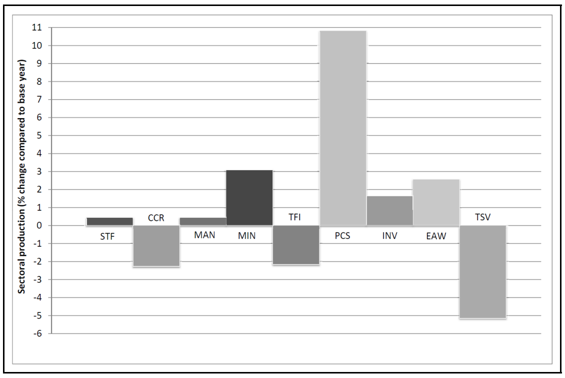

Figure 3: Sectoral real production effect of a 50% increase in road density

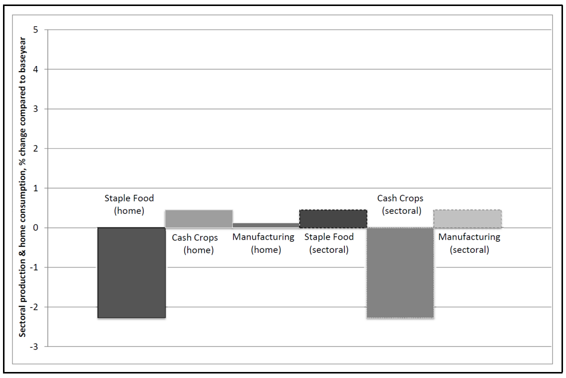

Figure 4: Marketed and home consumed production effect of a 50% increase in road density

In figure 4 we see that at the sectoral level home consumed production evolves in correspondence to marketed production.[17] This implies that in the sectors where home consumption is possible, the share of home consumption stays more or less constant in contrast to the theoretical predictions. Nonetheless, as the production in other sectors increases significantly, the share of home consumption in aggregate consumption decreases correspondingly. Given the fact that home produced agricultural products are by assumption perfect substitutes for marketed agricultural products, home consumption is always preferable to marketed goods in agricultural sectors as long as there exist positive transport costs inducing a higher relative price for marketed goods. Nevertheless, the welfare gains from better infrastructure allow the households to increase their consumption of market-only goods. Thus we see a change in the composition of the aggregate consumption bundles of both households in favor of marketed goods.

Figure 5 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 constant or slightly declining importance in the consumption bundles of both households.

As the government collects the welfare gains in form of an endogenous tax on infrastructure

[17]Note that home consumption is only possible in agricultural sectors and very basic manufacturing.

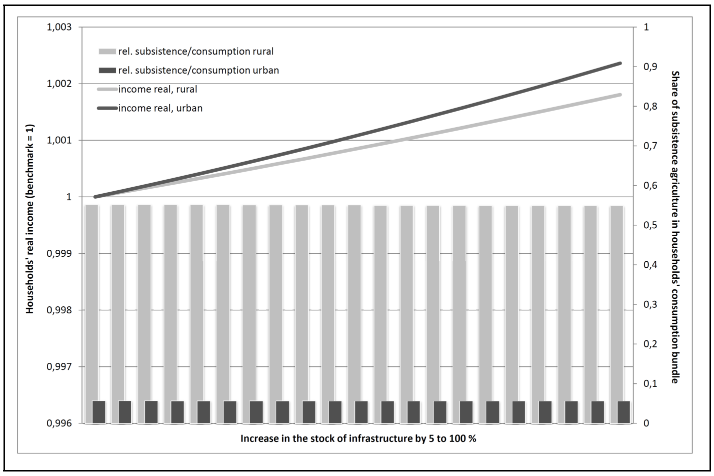

Figure 5: Home consumption of the two household groups

in this baseline scenario, the investment programme is (nearly) distribution neutral.

6.4. 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.

At the aggregate level, the welfare effect depends significantly on the assumption that households benefit directly from better transport infrastructure but not on the assumption which household receives the welfare gains directly. Figures D.9 and D.10 in Appendix D show that the aggregate welfare effect is much higher if the welfare effects are completely assigned to private households. However, whether all households benefit or only rural households does not have an influence on the aggregate effect on welfare, production and home consumption. This assumption obviously has an influence on distribution.

Compared to the neutral scenario we see a more pronounced drop in the aggregate relation of home consumption to marketed production because private households demand more transport intensive goods compared to the government. Thus the transport cost effect has a higher impact on the composition of consumption bundles if private households dispose of the additionally available resources. The effect on home consumption at the household level is shown in figures D.11 and D.12 in Appendix D.

6.5. Robustness

It is important to note that the quantitative results depend on a number of assumptions. Most importantly, the value of the additional infrastructure capital has been calculated on the basis of world average public investment prices. This assumption does not affect the relative results but the overall magnitude of the effects. The relative results and the proper working of the model might be sensitive with respect to the assumed elasticity of the trade and transport margin. As a robustness check we kept the level of investment constant and changed the elasticity parameter between 0.0005 and 0.01. The results are only affected in their magnitude but show a linear relationship to the elasticity parameter. The model compilation and solution are robust with respect to changes in the elasticity parameter.

7. Policy implications and conclusion

This paper shows 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 programs, 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. Theoretical contributions often mention a transport cost reducing effect from roads. Nonetheless, concrete quantitative results are scarce and unreliable. In addition, the theoretical reflections in the literature have not been translated into appropriate models for policy analysis.

This paper contributes to the existing literature on transport infrastructure in several ways: We show how the verbal theoretical considerations on the direct and indirect effects from better roads can be translated into a general equilibrium setup. We develop a small stylized model of transport infrastructure and apply the same methodology in a realistic CGE thereafter. In addition to this contribution in the field of CGE modeling we present empirical evidence for a clear and significant negative relationship between transport networks and trade and transport margins. We measure transport costs as the share of spending on trade and transport inputs in total sectoral output.

Simulations with the CGE model confirm that with increasing availability of roads the demand for labor and capital for transport declines. These factors move to 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 the assumption which households benefit directly from shorter traveling times and less goods lost 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. Especially if infrastructure programs are in favor of rural areas, the welfare effect clearly transcends the output effect.

The empirical and simulation results show that infrastructure investment programs are a well-suited instrument to support the development of a country as increased infrastructure has positive effects on production and welfare. However, infrastructure projects are extremely costly and the empirical literature emphasizes that efficient planning of such projects is of major importance. We clearly confirm this in our model simulations. Infrastructure affects the production sectors differently depending on their transport intensity and their factor input requirements. Especially manufacturing and capital-intensive activities benefit while agricultural sectors are less favored given the relative increase in wages. Hence, a pro-poor investment strategy especially in agricultural economies should target rural areas specifically. We do not confirm that a substantially higher proportion of agricultural goods is marketed as transport costs are still above zero but nonetheless the production and consumption of market-only consumption goods increases broadening the consumption possibilities. Another important factor to bear in mind is the increased demand for public and community services due to higher O&M spending. These require that at least part of the welfare gain from new roads is collected through taxes and used for maintenance.

Even though the simulation results correspond to the theoretical predictions, the magnitude of the effects is relatively small compared with the high investment costs. This is partly because the initial road density is so low that even doubling the availability leaves the country with a highly insufficient network. In addition, our robustness checks show that altering the elasticity parameter changes the magnitude of the effects. The direct effect from increased investment demand 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 requires reliable estimations not only of the road-elasticity of the transport margin but also on investment costs and depreciation as well as maintenance costs on the national level.

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

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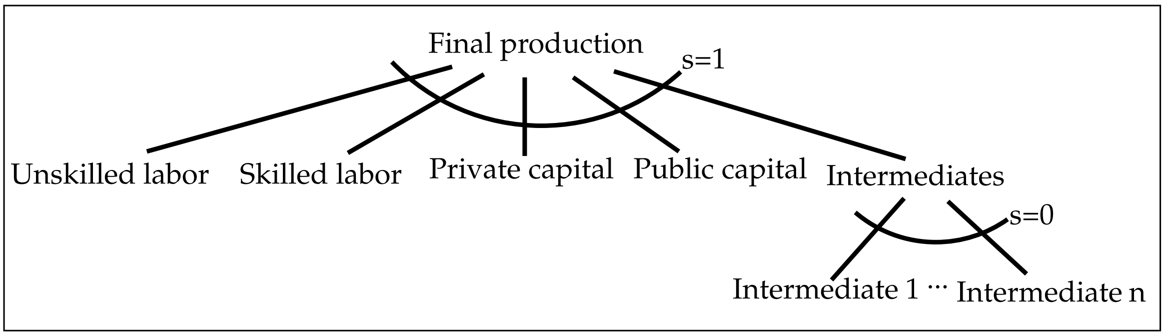
Appendix A. Comparison of the other CGE models for infrastructure

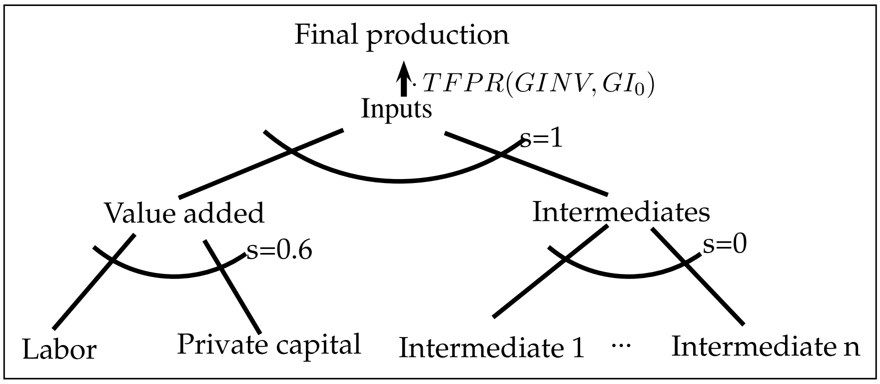
In Adam and Bevan [2006] public capital is provided by the rest of the world and enters the sectoral (Cobb-Douglas-) production functions as a factor of production. The respective exponent has been taken from an empirical study by Hulten [1996] and reflects the public capital-elasticity of output. In this setup there exists a limited possibility to substitute between labor, capital and public capital. Obviously, 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 A.6).

Figure A.6: Production function in Adam and Bevan (2006)



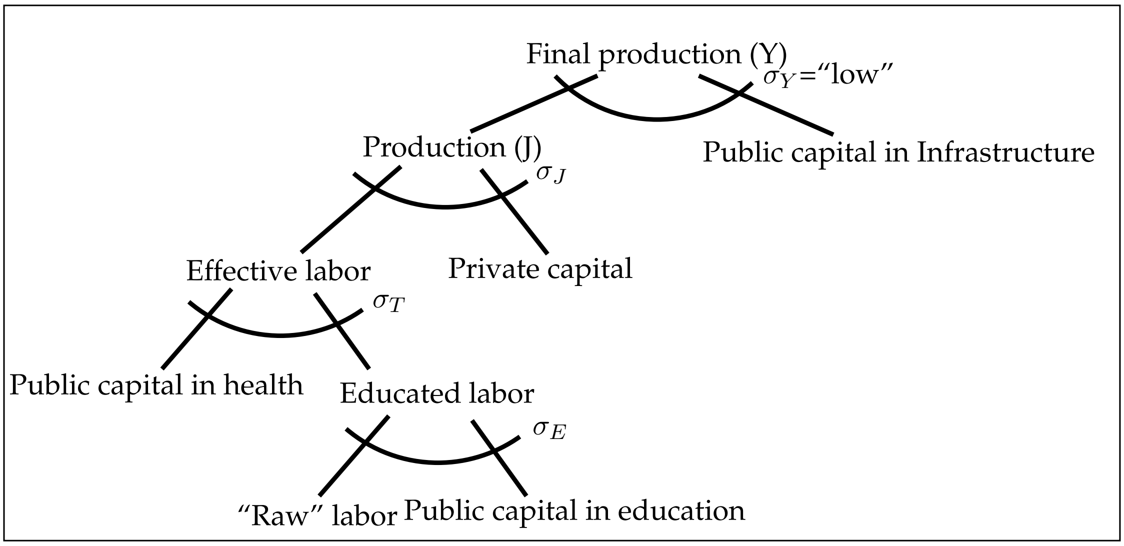
Levy [2006] uses a model which is, like the model used here, based on the IFPRI model [See Löfgren et al., 2002]. She introduces migration and external price setting into the model, which are special features of the Chad. Infrastructure is included in a comparable way as in Adam and Bevan [2006]: Infrastructure acts as a multiplier on all inputs in the production function. Thus it is assumed to increase total factor productivity, which is in line with the empirical findings in the production function literature. Infrastructure increases factor productivity by the factor $GINV^{0.2}$, which means that an additional percent of infrastructure increases factor productivity by approximately 0.2 percent. The shock is applied uniformely across sectors no matter which are the concrete infrastructure requirements. Her way of modeling infrastructure is, like the one of Adam and Bevan [2006] very much in line with the empirical findings of Aschauer [1989], Hulten [1996] and others. However, it is only capable to capture the effects of public capital in general but not the distinct effects of transport infrastructure through transport costs specifically.

Figure A.7: Production function in Levy (2006)



Agenor et al. [2008] use a simulation model which includes three different forms of public capital in 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 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 by construction 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 A.8). The authors are able to disaggregate the effects of a public capital shock with respect to households and sectors using a microsimulation model. Nonetheless, this modeling procedure is not able to capture asymmetric effects in the different sectors due to differences in transport intensities.

Figure A.8: Production function in Agénor et al. (2008)



Appendix B. Empirical specification

Table B.3: Descriptive statistics

	mg_{ag}	mg_{all}	Transp p. km^2	Population '000	Urbanisation	GDP_{cap}
Mean	0.12	0.12	0.57	81,651	0.58	11534
Minimum	0.02	0.04	0.01	3,554	0.13	148
Maximum	0.41	0.29	2.67	1,220,516	0.89	45478
Std. dev	0.08	0.07	0.71	223,083	0.22	12898

Appendix C. Model specification

Table C.4: Armington elasticities

sector	Elasticity of Substitution	Elasticity of Transformation
Staple Food	2.0	0.75
Cash Crops	1.5	4.0
Manufacturing	1.5	1.25
Mining	1.5	4.0
Tourism&Finance	0.2	0.2
Publ. Services	0.2	0.2
Capital Goods	0.5	0.5
Utilities	1.0	1.0
Trade&Transport	2.0	2.0

Appendix D. Results

Appendix D.1. Complete result listing - Redistribution of welfare gains through government

Table D.5: Infrastructure and transport demand and prices

% increase in infrastructure	demand for transport service (margin)	Price transport good	Price O&M	Price use of roads
Benchmark	1.0000	1.0000	1.0000	0.0824
5	0.9935	1.0000	1.0005	0.0683
10	0.9869	1.0001	1.0011	0.0682
15	0.9804	1.0001	1.0016	0.0682
20	0.9739	1.0002	1.0021	0.0682
25	0.9673	1.0002	1.0027	0.0682
30	0.9608	1.0003	1.0032	0.0682
35	0.9543	1.0003	1.0037	0.0682
40	0.9477	1.0004	1.0043	0.0682
45	0.9412	1.0004	1.0048	0.0682
50	0.9347	1.0004	1.0054	0.0682
55	0.9281	1.0005	1.0059	0.0682
60	0.9216	1.0005	1.0064	0.0682
65	0.9151	1.0006	1.0070	0.0682
70	0.9085	1.0006	1.0075	0.0682
75	0.9020	1.0007	1.0081	0.0682
80	0.8955	1.0008	1.0086	0.0682
85	0.8889	1.0008	1.0091	0.0681
90	0.8824	1.0009	1.0097	0.0681
95	0.8759	1.0009	1.0102	0.0681
100	0.8693	1.0010	1.0108	0.0681

Table D.6: Production, welfare and home consumption

% increase in infrastructure	Hicks equivalent welfare	change in welfare	Domestic production	change in domestic production	Home consumption	Home/ Marketed production
Benchmark	10798		26170		2456	0.0938
5	10799	1.0001	26174	1.0002	2455	0.0938
10	10800	1.0002	26179	1.0003	2455	0.0938
15	10801	1.0003	26183	1.0005	2454	0.0937
20	10802	1.0004	26188	1.0007	2453	0.0937
25	10803	1.0005	26192	1.0008	2453	0.0936
30	10804	1.0006	26196	1.0010	2452	0.0936
35	10805	1.0007	26200	1.0012	2451	0.0936
40	10806	1.0008	26205	1.0013	2451	0.0935
45	10808	1.0009	26209	1.0015	2450	0.0935
50	10809	1.0010	26213	1.0016	2449	0.0934
55	10810	1.0011	26217	1.0018	2449	0.0934
60	10811	1.0012	26221	1.0020	2448	0.0934
65	10812	1.0013	26225	1.0021	2448	0.0933
70	10814	1.0015	26229	1.0023	2447	0.0933
75	10815	1.0016	26233	1.0024	2446	0.0933
80	10816	1.0017	26237	1.0026	2446	0.0932
85	10817	1.0018	26241	1.0027	2445	0.0932
90	10819	1.0019	26245	1.0029	2444	0.0931
95	10820	1.0020	26249	1.0030	2444	0.0931
100	10821	1.0022	26253	1.0032	2443	0.0931

Table D.7: Factor prices

% increase in infrastructure	wage unskilled	wage skilled	land rent	capital rent
Benchmark	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0008	0.9999	0.9999
10	1.0000	1.0015	0.9998	0.9998
15	1.0001	1.0023	0.9997	0.9997
20	1.0001	1.0030	0.9995	0.9997
25	1.0001	1.0038	0.9994	0.9996
30	1.0001	1.0045	0.9993	0.9995
35	1.0001	1.0053	0.9992	0.9994
40	1.0002	1.0061	0.9990	0.9993
45	1.0002	1.0068	0.9989	0.9992
50	1.0002	1.0076	0.9988	0.9992
55	1.0002	1.0083	0.9987	0.9991
60	1.0002	1.0091	0.9986	0.9990
65	1.0002	1.0098	0.9984	0.9989
70	1.0003	1.0106	0.9983	0.9988
75	1.0003	1.0114	0.9982	0.9987
80	1.0003	1.0121	0.9981	0.9986
85	1.0003	1.0129	0.9980	0.9986
90	1.0003	1.0136	0.9978	0.9985
95	1.0004	1.0144	0.9977	0.9984
100	1.0004	1.0152	0.9976	0.9983

Table D.8: Sectoral production

% increase in infrastructure	Staple Food	Cash Crops	Manufacturing	Mining	Trade and financial services	Public and community services	Investment goods	Utilities	Transport services
Benchmark	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0005	0.9977	1.0004	1.0031	0.9978	1.0109	1.0016	1.0026	0.9948
10	1.0009	0.9954	1.0009	1.0062	0.9957	1.0218	1.0033	1.0052	0.9897
15	1.0014	0.9931	1.0013	1.0093	0.9935	1.0326	1.0049	1.0077	0.9845
20	1.0018	0.9908	1.0018	1.0124	0.9913	1.0435	1.0066	1.0103	0.9794
25	1.0022	0.9885	1.0022	1.0155	0.9892	1.0543	1.0082	1.0129	0.9742
30	1.0027	0.9863	1.0027	1.0186	0.9870	1.0651	1.0098	1.0155	0.9691
35	1.0031	0.9840	1.0031	1.0217	0.9849	1.0759	1.0115	1.0180	0.9639
40	1.0036	0.9817	1.0036	1.0248	0.9827	1.0867	1.0131	1.0206	0.9588
45	1.0040	0.9795	1.0040	1.0279	0.9805	1.0975	1.0147	1.0232	0.9536
50	1.0045	0.9772	1.0045	1.0310	0.9783	1.1082	1.0164	1.0258	0.9485
55	1.0049	0.9750	1.0049	1.0341	0.9762	1.1190	1.0180	1.0283	0.9433
60	1.0053	0.9728	1.0054	1.0372	0.9740	1.1297	1.0196	1.0309	0.9382
65	1.0058	0.9705	1.0058	1.0403	0.9718	1.1404	1.0212	1.0335	0.9330
70	1.0062	0.9683	1.0063	1.0434	0.9697	1.1512	1.0228	1.0361	0.9279
75	1.0066	0.9661	1.0067	1.0466	0.9675	1.1618	1.0245	1.0386	0.9227
80	1.0071	0.9639	1.0072	1.0497	0.9653	1.1725	1.0261	1.0412	0.9176
85	1.0075	0.9617	1.0076	1.0528	0.9632	1.1832	1.0277	1.0438	0.9124
90	1.0079	0.9595	1.0081	1.0559	0.9610	1.1938	1.0293	1.0464	0.9073
95	1.0084	0.9573	1.0085	1.0591	0.9588	1.2045	1.0309	1.0489	0.9021
100	1.0088	0.9552	1.0090	1.0622	0.9566	1.2151	1.0325	1.0515	0.8970

Table D.9: Sectoral home consumption

% increase in infrastructure	Staple Food	Cash Crops	Manufacturing
5	1.000512	0.99743	1.000442
10	1.00102	0.994867	1.000884
15	1.001526	0.992311	1.001326
20	1.002029	0.989764	1.001769
25	1.00253	0.987224	1.002212
30	1.003027	0.984692	1.002656
35	1.003522	0.982167	1.0031
40	1.004014	0.979651	1.003545
45	1.004503	0.977142	1.00399
50	1.00499	0.974641	1.004435
55	1.005473	0.972147	1.004881
60	1.005954	0.969662	1.005327
65	1.006432	0.967185	1.005774
70	1.006907	0.964715	1.006221
75	1.007379	0.962254	1.006669
80	1.007848	0.9598	1.007117
85	1.008314	0.957355	1.007565
90	1.008778	0.954918	1.008014
95	1.009239	0.952488	1.008463
100	1.009696	0.950067	1.008913

Table D.10: Income distribution

% increase in infrastructure	income real, rural	income real, urban	income urban/rural	rel. subsistence/ consumption rural	rel. subsistence/ consumption urban
Benchmark	1.0000	1.0000	3.1820	0.5519	0.0570
5	1.0001	1.0001	3.1820	0.5518	0.0569
10	1.0002	1.0002	3.1821	0.5516	0.0569
15	1.0002	1.0003	3.1822	0.5515	0.0568
20	1.0003	1.0004	3.1822	0.5514	0.0568
25	1.0004	1.0005	3.1823	0.5512	0.0567
30	1.0005	1.0006	3.1824	0.5511	0.0567
35	1.0006	1.0007	3.1825	0.5509	0.0566
40	1.0007	1.0009	3.1825	0.5508	0.0566
45	1.0008	1.0010	3.1826	0.5506	0.0565
50	1.0009	1.0011	3.1827	0.5505	0.0565
55	1.0009	1.0012	3.1828	0.5504	0.0565
60	1.0010	1.0013	3.1829	0.5502	0.0564
65	1.0011	1.0014	3.1830	0.5501	0.0564
70	1.0012	1.0016	3.1831	0.5499	0.0563
75	1.0013	1.0017	3.1832	0.5498	0.0563
80	1.0014	1.0018	3.1833	0.5496	0.0562
85	1.0015	1.0020	3.1834	0.5495	0.0562
90	1.0016	1.0021	3.1835	0.5493	0.0561
95	1.0017	1.0022	3.1836	0.5492	0.0561
100	1.0018	1.0024	3.1837	0.5490	0.0560

Appendix D.2. Alternative welfare allocation scenarios

Figure D.11: All households benefit

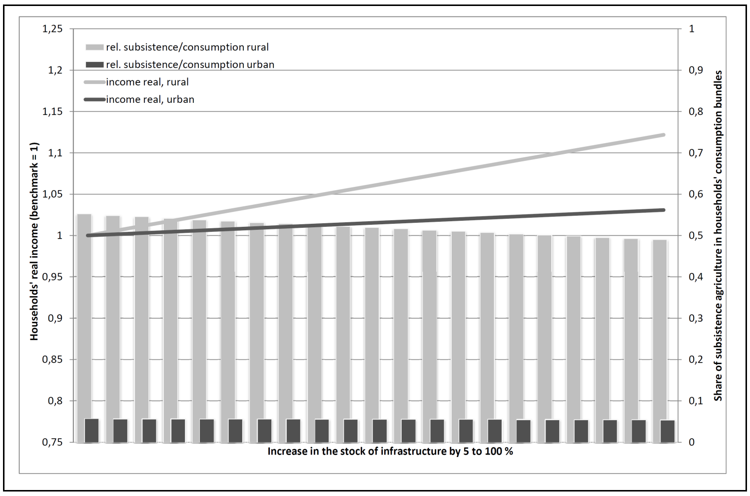


Figure D.9: All households benefit

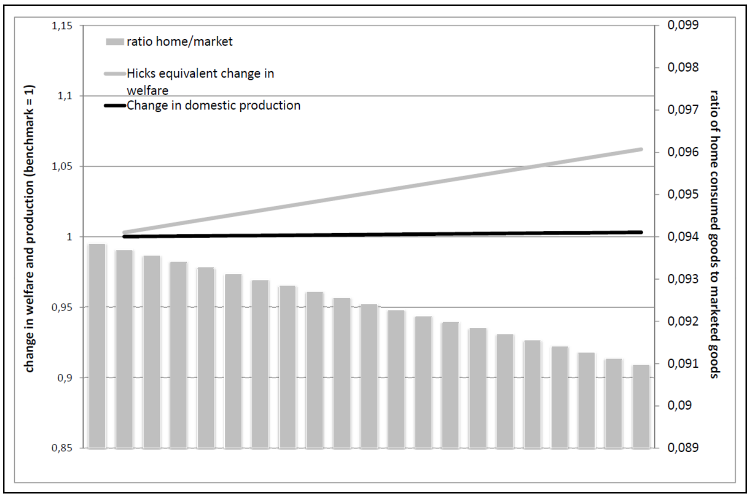


Figure D.10: Only rural gains

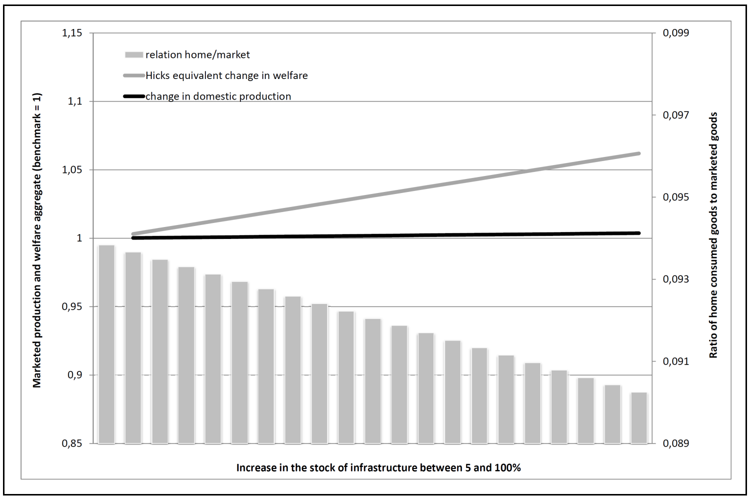


Figure D.12: Only rural gains