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Title: General equilibrium impact evaluation of road sector investment projects in Ghana*

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Abstract:

This study introduces an integrated economy-wide simulation framework for evaluation of capital road works for existing roads and highways, which formalizes transmission mechanisms and captures important static and dynamic spillover effects, and thereby allows for measurement of lifetime net benefits. The current CGE-RONET model framework bridges the gap between partial equilibrium simulation models in the engineering tradition (with a focus on "first order" effects), and general equilibrium simulation models in the economics tradition (with a focus on socioeconomic spillover effects), and thereby attempts to capture the main transmission mechanism between capital road works, road degradation, vehicle operating costs (VOC), transport sector productivity, and socioeconomic outcome variables. The study addresses several issues including project vs. program evaluation, explicit specification of transmission mechanism(s), distinction between new construction and other capital road works, and measurement of lifetime net benefits as a function of road degradation and planned future sequences of capital road works. The CGE-RONET model integrates the Road Network Evaluation Tools (RONET) transport model within a dynamically-recursive Computable General Equilibrium (CGE) model of the 1-2-3 type. It is calibrated on the basis of a 2004 Ghana SAM (Jensen, van den Andel & Duncan 2008). The analysis suggests that the planned future sequence of capital road works is crucial for (evaluating) the impact of current capital road works; Dynamic effects may account for >95 percent of the total GDP impact; Socioeconomic spillover effects may account for half of the total GDP impact. It is therefore crucial to account for dynamic and spillover effects when evaluating the global impact of capital road works. This rules out ex post methodologies, including the treatment-effect method, which cannot account for socioeconomic spillover effects or dynamic effects (in a timely fashion).

1. Introduction

The importance of public infrastructure capital, for economic development, has been recognized, for a long time, by both academics and policy makers (Calderón & Servén 2004, 2008). Public infrastructure may stimulate economic development, directly, through its impact on the cost and availability of infrastructure services, and, indirectly, through its impact on (national and foreign) agents' willingness to invest in the domestic economy, and through its impact on international competitiveness and world market integration. While the critical importance of public infrastructure development has been recognized for a long time, policy makers have been hesitant to commit scarce resources for infrastructure development. This is, in no small measure, due to the combination of high (current) investment costs, and the uncertainty which surrounds the magnitude of (future) socioeconomic benefits.

Economic evaluation is a key issue in the economics literature. Several methodologies have been applied for economic evaluation of public infrastructure policy. A basic distinction may be drawn between ex post econometrics-based evaluation studies and ex ante simulation-based evaluation studies. Another basic distinction may be drawn between program studies and specific project studies. A third distinction, specific to road and highway infrastructure, may be drawn between new construction and other capital road works, including periodic maintenance and re-construction, which are associated with existing roads and highways. This paper will study ex ante simulation-based socioeconomic evaluation of road and highway projects, with a focus on evaluating capital road works for existing roads and highways.[1]

Ex post econometric evaluation studies of public (road and highway) infrastructure can be categorized into "program studies" and "project studies". The program studies focus on evaluating the effect of aggregate (road and highway) infrastructure programs, while the project studies focus on evaluating specific road and highway projects. The "program studies" rely on country-specific time-series and regional panel datasets, with the purpose of estimating production functions (Aschauer, 1989, Munnell 1990a, 1990b, Garcia-Mila & McGuire 1992, Holtz-Eakin 1994, Holtz-Eakin & Lovely 1994, Evans & Karras 1994, Kocherlakota & Yi 1996, 1997, Fernald 1999, Puig-Junoy 2001, Kemmerling & Stephan 2002, Delgado & Alvarez 2007) and cost functions (Berndt & Hansson 1992, Lynde & Richmond 1992, Shah 1992, Nadiri & Mamuneas 1994, Morrison & Schwartz 1996, Moreno, Lopez-Bazo & Artis 2002, Albala-Bertrand & Mamatzakis 2004, Cohen & Morrison Paul 2004, Ezcurra, Gil, Pascual & Rapun 2005). The "project studies", typically, rely on the so-called treatment-effect methodology (van de Walle & Cratty 2002, Lokshin & Yemtsov 2005, van de Walle &

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[1] However, the methodology of the current paper may, just as well, be applied to program evaluation for existing roads and highways.

Mu 2007). Program studies, including production function and cost function studies, are based on the underlying assumption that public infrastructure capital is a production factor, which enters, directly, in firm's production and cost functions. Treatment-effect studies do not rely on restrictive assumptions about economic structure. However, the treatment-effect methodology suffers from the major weakness, that it ignores important spillover effects along spatial and time dimensions.

Ex ante simulation studies of roads and highways can be categorized into an "economics tradition" and an "engineering tradition". Simulation studies in the economics tradition, typically, rely on general equilibrium methodologies, while simulation studies in the engineering tradition, typically, rely on partial equilibrium methodologies. A large part of the general equilibrium studies, in the economics tradition, consists of multi-sector static-comparative regional studies with a focus on spatial aspects of road and highway projects (Buckley 1992, Bröcker 1998, Haddad & Kilkenny 1998, Hewings 1999, Bröcker & Schneider 2002, Haddad & Hewings 2005), while a smaller part of the literature consists of macro-level intertemporal simulation studies (Rioja 1999, 2003a, 2003b). The static-comparative simulation studies, typically, evaluate specific highway projects, while the intertemporal simulation studies, typically, aims at computing optimal levels of road and highway infrastructure. In general, simulation-based evaluation studies in the economics tradition focus on measuring short and long term outcomes. The calculation of lifetime benefits is, typically, ignored.

In contrast, the engineering tradition for simulation-based evaluation focuses, explicitly, on measuring lifetime benefits (Friedman 2003, Archondo-Callao 2009). Accordingly, studies in this tradition, account, explicitly, for the time dimension of benefits from road and highway projects. The focus of these studies is, typically, on dynamic road degradation and vehicle operating cost (VOC) savings associated with capital road works. Evaluation is based on net present value (NPV) calculations of VOC savings, over the lifetime of the road project. The engineering tradition also distinguishes between different types of capital road works, including new construction, re-construction and periodic maintenance. In contrast, simulation-based evaluation studies, in the economics tradition, typically, focus on evaluation of new construction of roads and highways, while little attention is given to other components of road and highway programs. [2]

A few general equilibrium simulation studies have employed dynamic multi-sector models to evaluate the impact of transport sector programs (Feltenstein & Ha 1999) and specific highway projects (Kim, Hewings & Hong 2004). The latter study develops an integrated framework, which accounts for both spatial and

[2] Notable exceptions are the studies by Rioja (2003a, 2003b). They focus, broadly, on public infrastructure, with a basic distinction between new investment and maintenance costs. They employ stylized macro-level intertemporal CGE model frameworks, which are calibrated on the basis of parameter estimates from various Latin American countries, and they argue that the optimal level of maintenance depends on the level of new construction, and, more importantly, that low effectiveness in existing infrastructure may result in negative returns to new construction.

dynamic aspects associated with new construction of highways. In particular, they integrate a transport model, which models accessibility based on minimum travel distances, within a dynamically-recursive interregional general equilibrium model for Korea. In line with the literature in the economics tradition, highway infrastructure capital is assumed to be an unpaid production factor. However, the highway infrastructure capital stock is substituted for the accessibility index in firm's production functions. In this way, the authors attempt to model firm's improved access to transportation services which results from new construction of highways.

This study attempts to bridge the gap between the engineering tradition and the economics tradition for simulation-based evaluation of road and highway projects, by developing a combined dynamic multi-sector model which allows for the calculation of socioeconomic lifetime benefits. However, in contrast to most previous simulation-based project studies, this study focuses on evaluating the impact of capital road works associated with existing roads and highways. The current framework does not, explicitly, model the spatial dimension of the transportation network (which is particularly important for evaluation of new road construction in large and widely dispersed economies). Instead, it focuses on evaluating the impact of VOC savings from re-construction and periodic maintenance of existing roads and highways. The transmission mechanism runs from VOC savings (and associated productivity gains in the transport sector), through reduced transportation costs and marketing margins for both producers and consumers, to socioeconomic outcome variables. Accordingly, this study attempts to model improved access to transportation services for firms and consumers, explicitly, instead of assuming that public infrastructure capital enters, directly, in firm's production functions.

The combined ex ante impact evaluation tool, which is presented in this study, consists of (i) a dynamically-recursive Computable General Equilibrium (CGE) model, which is based on a static CGE model of the 1-2-3 type with marketing margins (Arndt, Jensen, Robinson & Tarp 2000; Löfgren, Harris & Robinson 2002), and (ii) a partial equilibrium transport model, which is based on the Road Network Evaluation Tools (RONET) model (Archondo-Callao 2009). The transport model is used to compute dynamic sequences of transport sector VOC savings (productivity gains) and road project costs. These dynamic sequences of benefits and costs are, subsequently, imposed on the dynamically-recursive CGE model to compute lifetime socioeconomic net benefits, in NPV terms, over a 15 year time horizon.

The combined CGE-RONET framework is constructed around structural equations which model the gradual degradation of road quality over time (based on road surface type, and initial conditions including initial roughness and the strength of the structural foundation). The framework also models the links between (i) road project costs and road quality, and between (ii) road quality and vehicle operating costs. Accordingly, this study puts focus on the importance of road quality. Finally, the focus of the CGE-RONET framework on the transmission mechanism running from road projects to voc savings and transport sector productivity improvements, i.e. without having to specify a direct link between road projects and the productivity of non-transport production sectors, means that direct benefits, accruing from reduced transportation costs, are shared between both producers and consumers.[3]

This main purpose of this study is to introduce an integrated economy-wide framework for evaluation of road and highway projects (and programs), which formalizes transmission mechanisms and captures important static and dynamic spillover effects, and thereby allows for appropriate measurement of lifetime net benefits flowing from road projects and programs. In addition, this study addresses a number of issues in the literature. First, it addresses the issue of evaluating general infrastructure programs vs. specific road projects, including the distinction between different types of capital road works. Second, it addresses the issue of, explicitly, specifying the transmission mechanism(s) through which road and highway infrastructure projects affects socioeconomic outcomes, including taking account of spillover effects (along spatial and time dimensions). Third, it raises the issue of accounting for planned future sequences of capital road works, in the measurement of socioeconomic lifetime benefits from current capital road works. In particular, the current study points to the importance of accounting for future (politically determined) minimum road quality levels in the evaluation of current capital road works.

Finally, this study raises the issue of choosing between ex ante simulation models and ex post econometric tools for impact evaluation of specific road and highway projects. It points to the importance of estimating parameters and/or simulating outcome measures which are economically interesting to government agencies and aid donors. In particular, it points to the need for timely evaluation of lifetime socioeconomic benefits from infrastructure projects which may extend over the very long term (>15 years). In this way, it provides an example of the limitations of the expanded focus of (unilateral and multilateral) donor agencies on the treatment-effect methodology, exemplified by the Development Impact Evaluation (DIME) initiative of the World Bank, and the International Initiative for Impact Evaluation (3ie) which includes several (unilateral and multilateral) donor agencies and private NGOs as core members. The lifetime net benefits of (road and highway) development projects with important dynamic effects cannot be evaluated by the

[3] The RONET model (Archondo-Callao 2009) has been developed on the basis of the HDM-4 model (PIARC 2005). The idea of integrating the RONET/HDM-4 transport model within a general equilibrium framework has been developed, independently, in another recent study (World Bank 2008). However, the latter study focuses narrowly on new road construction. Furthermore, the latter study does not, explicitly, take account of the time dimension, including future capital road works which may affect the impact of current (new construction) capital road works. It is, therefore, unable to capture the lifetime benefits of road and highway projects. Furthermore, the measurement of productivity gains focuses, narrowly, on business related gains, including reduced marketing costs for final products, without considering the direct gains for producers and final consumers in terms of reduced transportation costs.

simple non-structural treatment-effect methodology (in a timely manner), since it does not account for structural variation in effects over time (e.g. of road projects, due to road degradation and variation in future capital road works strategies).[4]

The project-specific variation in the benefits of aid-financed road projects (due to variation in e.g. traffic intensity, initial road quality measured by roughness level and strength of structural foundation, road surface type) and the associated non-linear variation in the cost of capital road works, also points to the need for separate analyzes of aid effectiveness across the wide spectrum of developing countries and the wide spectrum of aid-financed projects and programs. In particular, the assumption of a constant global average effect of aggregate aid inflows across countries and time periods (with some allowance for variation in aggregate policy indices defined, mainly, in terms of trade openness and fiscal prudence) may explain why macro-econometric results are very sensitive to the choice of sample and functional specification (Easterly, Levine & Roodman 2004, Roodman 2007).

The combined CGE-RONET framework is implemented for Ghana. The CGE model is calibrated on the basis of a recently developed 2004 Ghana SAM (Jensen, van den Andel & Duncan 2008), while the transport model is parameterized on the basis of a 2005 Ghana RONET model (MoT 2008). Subsequently, the Ghana CGE-RONET model framework is applied to evaluate the lifetime socioeconomic benefits from current capital road works, conditional on planned future sequences of capital road works.

Results are presented in terms of macroeconomic multipliers, including changes in (the net present value of) real GDP, household welfare and poverty gap, as well as the increase in employment years and the reduction in poverty years (per GHC spent on the road project). The analysis is going to show that the impact of current capital road works depends, crucially, on planned future sequences of capital road works. Accordingly, the (isolated) economic impact of current capital road works for existing roads and highways depends, crucially, on the frequency of future periodic maintenance and re-construction (the dynamic counterfactual). This finding is important. It implies that static impact evaluation methodologies are, fundamentally, flawed in the context of road sector projects and programs.

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[4] This discussion also points to the need for expanding the implicit reference of the term “impact evaluation” to a wider set of methodologies. The term seems to have been monopolized by treatment-effect studies, due to their (seemingly unique) ability to attribute observed outcomes to specific projects. However, their limitations in terms of geographical and dynamic coverage means that their ability to capture the global impact of development projects rely on structural assumptions regarding static and dynamic spillover effects which are, typically, not explicitly stated. In this paper, the term “impact evaluation” is extended to cover all ex post econometric methodologies and ex ante simulation model methodologies, which are used, in the academic literature, to evaluate the impact of road projects and road programs.

The rest of the paper is organized as follows: Section 2 contains a methodological discussion; Section 3 contains model description and calibration; Section 4 contains results; and section 5 contains conclusions.

2. Methodology for evaluation of public road and highway projects

The basic reason for the public provision of goods and services is that they will not be supplied by the private market. The classic example is a non-divisible good or service, which is provided to a community without the possibility for exclusion of users. Highway systems does allow for exclusion of users. As a consequence, private provision of highway services has increased over the past 20 years in developed countries as well as in some developing (mainly Latin American) countries. Nevertheless, there is an active discussion about whether the reduction in public infrastructure capital has been fully compensated by increasing private infrastructure capital (Calderon & Serven 2004).

For low-income Sub-Saharan African countries, there is little evidence to support the notion that private agents will step in to compensate for reduced public highway spending.[5] Even in the case where it is possible to extract sufficient rents to cover construction and maintenance costs, the exclusion of highway users (and the loss of scale economies due to the low cost of marginal users) associated with private provision of highway services, means that public infrastructure provision is likely to be the most efficient way to supply highway services in low-income Sub-Saharan African countries. Accordingly, public provision of road and highway infrastructure is likely to dominate in Sub-Saharan African countries over the foreseeable future. The current study will focus, narrowly, on the evaluation of public road and highway infrastructure projects (in Ghana), without taking account of the possibility for private sector participation.

The majority of the existing econometric literature focuses on evaluating (road and highway) infrastructure programs as opposed to specific road and highway projects. The main exception is the recent line of ex post treatment-effect studies of rural road projects (van de Walle & Cratty 2002, Lokshin & Yemtsov 2005, van de Walle & Mu 2007). The treatment-effect methodology is, radically, different from the simulation methodology employed in this study. Accordingly, it does not rely on the specification of economic structure for evaluation purposes. Instead, it relies on the assumption of randomization or the existence of (other) appropriate instrumental variables for identification purposes (Imbens & Angrist 1994, Angrist, Imbens & Rubin 1996). The treatment-effect literature has been criticized, on general grounds, for its lack of economic structure (Heckman 2006a). In particular, it has been argued that the treatment-effect methodology 'lacks the ability to provide explanations for estimated "effects" grounded in economics or to conduct welfare economics' (ibid., p. 4788), and that 'parameters do not lend themselves to extrapolation

[5] Private infrastructure provision may substitute for public infrastructure spending under special circumstances, i.e. when it is possible to extract sufficient rents to cover construction and maintenance costs. One example is the toll road which links Maputo, located in the southern part of Mozambique, to the South African highway system.

out of sample or to accurate forecasts of impacts of other policies besides the ones being empirically investigated' (ibid., p. 4788). Accordingly, the lack of economic structure implies that the treatment-effect methodology can only be used for evaluation of specific (road and highway) projects and programs.

It has also been argued that the treatment-effect 'literature is often unclear in stating what economic question the estimated parameters answer' (Heckman 2006a, p. 4784), and that 'the literature is often unclear as to what variables to include in conditioning sets and what variables to exclude and the conditions under which an estimator identifies an economically interesting parameter' (ibid., p. 4784). This seems to be, particularly, problematic for treatment-effect studies of road and highway projects. These studies, typically, focus on evaluation of aid-financed road projects in developing countries. Nevertheless, they contain no discussion of the type of parameters, which are relevant for government agencies and unilateral or multilateral aid donors. In particular, they contain no references to the fact that they only estimate average treatment effects (ATE) within the specific sample, i.e. for individuals or households living close to the road and highway projects.[6]

The treatment-effect methodology relies, fundamentally, on the assumption that samples represent independent and identically distributed draws from the underlying population (random sampling). This rule out evaluation of projects and programs with general equilibrium spillover effects, e.g. impact evaluation of tuition policy on school enrollment (Heckman, Lochner & Taber 1998). Road and highway projects are also characterized by general equilibrium spillover effects, e.g. regional and national changes in transportation costs and marketing margins, and regional and national sector reallocation of primary production factors. The treatment-effect methodology is, therefore, unsuited for evaluating road and highway projects. Treatment-effect studies do recognize the importance of spillover effects. However, instead of accounting for the spillover effects as an added benefit (or cost) these studies consider spillover effects to be a nuisance (in relation to the specification of e.g. control villages).

Since regional and national spillover effects are important for road projects, the treatment-effect methodology cannot be used to evaluate the global impact of road and highway projects in a spatial sense. Similarly, treatment-effect studies only account for the impact of dynamic effects during the period of investigation (e.g. the third year after completion of the road project). As a consequence, they do not

[6] For a discussion of necessary methodological extensions to the treatment-effect methodology to allow for extrapolation out of sample and for estimating global average treatment effects, including the potential need for randomization at the national and international level and the specification of structural models to accompany randomized experiments (where experimental design, based on the underlying theory, is used, instrumentally, for identification purposes, in order to allow randomized experiments to be used as a research tool), see Duflo, Glennerster & Kremer (2008).

account for the net present value of accumulated benefits, i.e. the lifetime benefits of the road project. Hence, the treatment-effect methodology cannot be used to measure the global impact in a dynamic sense either.[7]

In general, the treatment-effect paradigm can only be used to estimate the local impact (i.e. the impact at a given location over a limited time period) of a road project, while it is fundamentally flawed in relation to estimating the global (spatial and dynamic) impact of road projects and programs (i.e. the net present value of current and future regional and national net benefits). In fact, from a general point of view, ex post (econometric) impact evaluation of road and highway projects does not seem to make much sense. The purpose of evaluating specific projects is to ensure that current funds are being spent wisely. However, road and highway projects have dynamic effects which may extend over the very long term (15-20 years). In order to achieve timely impact evaluation of road and highway projects (which, at the same time, take account of the important dynamic effects), it is necessary to employ ex ante (simulation) evaluation methods.[8]

In contrast to the treatment-effect methodology, the simulation methodology relies, fundamentally, on the specification of economic structure for evaluation purposes. This implies that the transmission of economic effects has to be specified, explicitly. The econometric literature (apart from the treatment-effect studies) has, with a few important exceptions (Fernald 1999), by-passed this issue and assumed that public infrastructure capital enters directly in the production function or cost function.[9] This approach has been picked up by the simulation studies in the economics tradition. Most of these studies model (highway) infrastructure capital as an unpaid production factor. These studies, typically, focus on spatial aspects associated with new construction of highways, and therefore substitute infrastructure capital with an accessibility measure, which is based on minimum travel distances. While the underlying idea is clear – that new construction of highways increases accessibility – the implementation is not. These studies simply assume that their chosen accessibility measure (inverse function of minimum travel distance) leads to

[7] For a discussion of how the treatment-effect methodology may be applied to dynamic issues, e.g. program impact on poverty transitions, see Ravallion (2008).

[8] The treatment-effect methodology could, potentially, be used to benchmark simulation-based impact evaluations of road and highway projects, by providing a lower bound for the impact in a given period, e.g. the third year after the capital road work was undertaken. In principle, this lower bound may turn out to be larger than the simulated period specific impact, since simulations rely on the explicit specification of a limited number of transmission mechanisms from "first order" effects of capital road works to socioeconomic outcomes. If such a case arose, it would be a sign that important (local) transmission mechanisms had been ignored in the specification of the simulation model.

[9] Few econometric studies attempt to model the specific transmission mechanism of the causal link running from public infrastructure capital to economic outcome variables. A notable exception is the influential econometric study by Fernald (1999), which points to the importance of including transportation services in the production function, and of modeling sector-specific transportation services as a function of highway capital and the sector-specific vehicle-intensity, when evaluating the impact of infrastructure programs.

Hicks-neutral productivity changes for all production sectors (depending on a chosen set of elasticities). No consideration is given to the specific transmission of economic effects.

In contrast to the economics tradition, the partial equilibrium (PE) simulation studies in the engineering tradition has focused, narrowly, on measuring the "first order" consequences of capital road works – static and dynamic consequences which form the basis for the transmission of economic effects to the rest of the economy. The simulation studies in the engineering tradition indicates, that there exist several types of first order effects including travel time reductions, vehicle operating cost (voc) savings and safety improvements (OECD 2002). Measuring the global impact of capital road works would involve modeling all transmission mechanisms, running from capital road works, through each of these first order effects, to ultimate socio-economic outcomes. The simulation literature in the economics tradition, with its focus on general equilibrium models, is well suited for capturing (pecuniary) spillover effects from capital road works. In principle, the integration of the PE methodology from the engineering tradition and the GE methodology from the economics tradition, therefore, allows for measuring the "global benefits" from road and highway projects, including spatial (within-period) spillover effects and dynamic (between-period) spillover effects. The fundamental idea of the current paper is to integrate a dynamic transport model in the engineering tradition and a dynamic CGE model in the economics tradition, and thereby attempt to capture the main static and dynamic socio-economic (spillover) effects of road and highway projects, which will allow for appropriate calculation of net present value outcome measures of interest to policy makers and aid donors.

Several socio-economic transmission mechanisms may be associated with travel time reductions (or travel time increases). Changes in travel time may lead to changes in labor supply. For low-income Sub-Saharan African countries, extensive unemployment and/or underemployment means that labor supply is unlikely to act as a resource constraint. Hence, the increased labor supply, which may follow from travel time reductions, is unlikely to have an impact on firm's production decisions. Travel time reduction is also related to the important concept of accessibility. The concept of accessibility may cover several socio-economic transmission mechanisms including reduced inventory need and increased operating scale for firms, and potential congestion effects arising from road and highway projects. The concept of accessibility also covers reduced turn-around times and, hence, reduced transportation costs, marketing margins, and primary factor input needs. In this sense, the transmission mechanisms of accessibility may overlap with the transmission mechanisms of VOC savings (see below). As already mentioned, the existing simulation literature in the economics tradition has focused, narrowly, on the concept of accessibility, but has refrained from modeling specific transmission mechanisms. Instead, they have assumed that changes in the abstract accessibility measure (measured as an inverse function of minimum travel distances) leads to

HICKS-neutral productivity changes for all production activities (including but not limited to transportation activities).

Accessibility considerations are likely to constitute an important part of the socio-economic transmission effects of reduced travel time associated with new construction of roads and highways. On the other hand, they are likely to constitute a smaller (but still important) part of the socio-economic transmission effects associated with other capital road works such as periodic maintenance and re-construction of existing roads and highways. In this paper (with its focus on existing roads and highways), accessibility is not, explicitly, modeled. Nevertheless, accessibility is (partly but not fully) captured by specific transmission mechanisms running through the impact of VOC savings and increased transport sector productivity on reduced transportation costs, marketing margins and primary factor input needs in the transportation activity.

For low-income Sub-Saharan African countries, voc savings is considered to be the most important first order effect and source of socio-economic transmission effects of capital road works. According to the World Bank, "consensus has been growing among highway administrators, economists and engineers, in developed and developing countries alike, on using the principle of total transport cost minimization as a basis for determining road construction and maintenance policies" (World Bank 2009). The main socio-economic transmission mechanism associated with voc savings, is that it changes the productivity of the transportation activity. Hence, voc savings represents the cost reduction for a given transport load of goods/persons over a given distance. The fundamental idea of the current paper is to use (dynamic sequences of) voc savings to calculate implied (dynamic sequences of) productivity gains in the transportation sector, to subsequently calculate implied (dynamic sequences of) outcome variables, and on this basis to calculate the NPV value of ultimate socio-economic outcome measures.

In the engineering tradition, simulation of voc costs is, typically, based on a roughness index of the road surface. In this paper, focus will be on the so-called International Roughness Index (IRI). Furthermore, simulation studies in the engineering tradition typically rely on functional relationships between voc costs and the roughness index. Increasing roughness leads to increasing voc costs. In this paper, focus will be on a reduced form (cubic polynomial) relationship between voc costs and the IRI roughness index (Archondo-Callao 2009). Simulation models in the engineering tradition may contain thousands of equations to model the degradation of various road surface types over time, as well as keeping track of various determinants of the rate of degradation (PIARC 2005). In this paper, focus will be on paved road types including cement/concrete, asphalt mix, and surface treatment roads.[10] Furthermore, focus will be on primary, secondary and tertiary road types. A relatively simple functional form will be employed where the only endogenous determinants of road degradation are the age of the road since the last major capital road work, and the strength of the structural foundation measured by a so-called structural number (Archondo-Callao 2009).[11]

Simulation models in the engineering tradition evaluate voc costs on the basis of individual cost components of road users. The construction and maintenance of roads and highways allows drivers to reach their destinations in less time, trucks deliver goods to market in less time, and producers (and consumers) have lower costs in terms of gasoline, drivers' salaries (and foregone wages), and depreciation of vehicles. Some large-scale simulation models in the engineering tradition keep track of these individual cost components of road users (PIARC 2005). In principle, this allows for detailed modeling of the cost structure of the transportation sector. Hence, the calculation of implied (dynamic sequences of) productivity gains in the transportation sector could be refined to include implied (dynamic sequences of) structural changes in the cost structure of the transportation activity. In this paper, focus will remain on implied (dynamic sequences of) HICKS-neutral productivity gains in the transportation activity.

As noted above, safety improvements also belong to the group of first order effects from road projects. Safety improvements may be an important policy target variable on par with increased accessibility and reduced vehicle operating costs. However, the socioeconomic impact of safety improvements is notoriously difficult to measure. Various methodologies have been established to measure the first order effect of "avoidance of death" including the gross output method, which calculates the net present value of future income or consumption losses, and the more widely used willingness to pay method, which relies on subjective estimates of individuals willingness to pay to reduce risk and avoid accidents. In either case, the estimation of these safety benefits remains uncertain. Furthermore, socioeconomic spillover effects, associated with safety improvements, are likely to be small compared to other spillover effects. The current paper abstracts from socioeconomic benefits due to improved road safety.

Since the current paper abstracts from issues related to accessibility and safety improvements, the current model framework does not capture the global impact of road projects. Nevertheless, voc savings is

[10] Unpaved road types include gravel and earth roads. Unpaved road types can, in principle, also be handled within the current model framework. However, degradation of gravel and earth roads is highly dependent on local environmental conditions, and this makes it difficult to derive proper functional specifications for road degradation of unpaved roads as opposed to paved roads where road degradation is more predictable.

[11] This relatively simple functional specification also includes exogenous determinants of road degradation, e.g. the environmental conditions measured by an environmental coefficient, and the traffic load measured by the number of standard axles.

considered to be the major first order effect of road projects in Sub-Saharan African countries, as well as the major channel for transmission of economic effects to the rest of the economy. Hence, the approach of the current paper is considered to be an improvement over previous methodologies for impact evaluation of road and highway projects, since it accounts for important dynamic effects (and general equilibrium spillover effects), and thereby allows for estimating the main lifetime benefits of road and highway projects.

In terms of the benefits of road and highway infrastructure, the condition of the roads may be just as important as the existence of the roads. Hence, the cost of transportation services to producers and consumers increases with degradation and reduced quality of the road. The econometric literature has not distinguished between different types of capital road works. In particular, no attempt has been made to distinguish between the impact of new construction of roads, and the impact of periodic maintenance and reconstruction of roads. And this in spite of the fact that it has, previously, been hypothesized that infrastructure problems (in the US, during the 1970s and 1980s) were not due to funding problems, but because "transportation programs have focused on new construction at the expense of repairs and maintenance" (Hulten & Schwab 1993, p. 271).

The majority of the existing (multi-sector) simulation literature focuses on evaluating the impact of specific "new construction" highway projects within a static CGE model framework (Haddad & Kilkenny 1998, Hewings 1999, Bröcker & Schneider 2002, Haddad & Hewings 2005) or a dynamic CGE model framework (Feltenstein & Ha 1999, Kim, Hewings & Hong 2004). Attempts have also been made to construct dynamic general equilibrium models, which were used to simulate the relative impact of new construction and maintenance costs (Rioja 2003a, 2003b). However, these studies did not specify structural equations for the transmission mechanism. Instead, they assumed that public infrastructure capital entered directly in the production function, and specified reduced form equations where the depreciation rate of public capital was a function of maintenance costs and private capital (proxy for the use of public capital), and where an ad hoc parameterization were used for the chosen functional form.

The exclusive focus on new construction is problematic for the existing simulation based literature in the economics tradition. First, it means that there is little existing knowledge about the socioeconomic impact of capital road works associated with existing roads and highways. Second, the exclusive focus on new construction (with a narrow focus on accessibility) doesn't allow for proper impact evaluation of "new construction" capital road works. In general, the existing simulation studies do not calculate the net present value of future benefits associated with current capital road works. This is a crucial problem. However, even if they did, their estimates would be flawed since they do not take account of the (planned) future sequence of capital road works (on the newly constructed road). In general, the net present value of future benefits associated with current capital road works, depends on the (planned) future sequence of capital road works (over the lifetime of the current capital road works). Hence, in the specification of the counterfactual for impact evaluation of new road construction, it is necessary to take account of the (planned) future sequence of capital road works, including periodic maintenance and re-construction. In this paper, the importance of accounting for the future sequence of capital road works is investigated in the context of impact evaluation of current capital road works for existing roads and highways.

Furthermore, this paper focuses on project evaluation as opposed to program evaluation. Since the methodology is an ex ante simulation methodology, it must, necessarily, rely on a set of simplifying assumptions. The road project to be evaluated is characterized by road characteristics (length of road segment, traffic intensity and traffic composition, initial surface type, initial roughness, initial structural foundation) and treatment characteristics (quality of periodic maintenance (overlay thickness) and re-construction measured by the ex post roughness level). On the other hand, since the current application employs a national economy-wide model (for Ghana), the regional geographical location of the road project is not taken into account.

Employing a national economy-wide simulation model implies, that the evaluation of capital road works will be based on structural economic characteristics at the national level. Increased productivity in the transportation sector, following from the capital road works, will lead to reduced transportation costs and marketing margins, and this will benefit all representative production activities (to the extent that they use transportation services as an intermediate input and incur marketing costs), and all representative consumers (to the extent that they consume transportation services). Furthermore, the surplus of primary production factors in the transportation activity will be efficiently reallocated among all representative production activities. In contrast, employing a regional simulation model will allow for measuring the impact on regional representative production activities and regional representative households. However, unless there is strong regional variation in economic structure, it is not clear that employing a regional model will have any major impact on the global economy-wide effects.

Attempts have, previously, been made to integrate transport models within regional static model frameworks, to evaluate the impact of new construction of highways. These types of models have mainly been developed for the large widespread Brazilian economy, where the construction of highways is crucial for the economic integration of a large number of dispersed regions with varying economic characteristics. It seems very likely that there will be added benefits associated with the modeling of regional variation in economic characteristics in the case of the large widespread Brazilian economy. However, it seems less obvious that there will be similar benefits associated with constructing a regional model framework for the smaller and less widespread Ghanaian economy.

In either case, the economy-wide simulation model approach will not capture structural economic characteristics at the local level. In the context of road and highway projects, this may be considered to be a weakness, since local variation in economic characteristics may be important for the transmission of economic effects (spillovers) to the rest of the economy. However, the importance of capturing local variation in economic characteristics is likely to vary with the type of road project. The impact of capital road works associated with primary and secondary roads are likely to depend mostly on regional and national (rather than local) economic characteristics, while the transmission of economic effects from capital road works associated with tertiary roads are likely to depend, more closely, on local economic characteristics.

While the economy-wide simulation model approach is likely to be better suited for impact evaluation of primary and secondary roads, the approach will also capture important (pecuniary) spillover effects associated with tertiary road projects, which may not captured by other methodologies (e.g. the treatment-effect methodology). In particular, imagine that the improvement of a tertiary road allows a truck to cut the travel time to and from a remote village into half, i.e. a 50% reduction in travel time. This implies a reduction in capital use (the truck being the capital stock in this transport sector example). An important part of the gains from road improvement (especially in developing countries) stems from the ability to reallocate scarce capital to other uses. In this case, the truck may use the time savings to make additional trips to other remote villages and, potentially, substitute for other trucks. This may lower the need for investment in new trucks (at the regional/national level), and, thereby, free up scarce capital for other uses, e.g. investment in food processing activities (at the regional/national level). Hence, the economy-wide model approach, which is employed in this paper, does capture important aspects of the global impact of remote tertiary roads with low traffic intensity, including static spillover effects in the form of efficient capital reallocation.

As the above example illustrates, the regional and national transmission of economic effects, working through efficient reallocation of scarce capital, is likely to be equally important for all types of road and highway projects. However, there are other (pecuniary) spillover effects, which cannot be, narrowly, associated with specific road and highway projects. While capital road works and improved transport sector productivity go hand in hand with lower transportation costs, relative transportation prices are unlikely to change very much, at the national level, in response to most road and highway projects.[12] The ability of economy-wide models to capture (pecuniary) spillover effects, in the form of changes in relative transportation prices, is related to the issue of project vs. program evaluation. While relative economy-wide transportation prices are unlikely to be affected (very much) by individual road projects, the (pecuniary) price externality of road projects may be captured by undertaking an overall road program evaluation. Road programs may combine a multitude of road projects, e.g. all capital road works for a given country during a given year. A subsequent decomposition analysis could then be used to derive the (average) impact of individual road projects (including the impact of program-induced relative price changes). This discussion points to the potential importance of accounting for overall road programs (and their impact on relative prices), when evaluating the (average) impact of specific road projects. While the current modeling approach can easily be adapted for program evaluation, this idea is not pursued, further, in this paper.

Outside the academic literature, some international institutions, notably the International Labor Organization (ILO), have continued to employ fixed-price general equilibrium models – better known as multiplier models – for the evaluation of the (employment) impact of road projects and programs. The multiplier model framework is in the Keynesian tradition. As such, it is focused, narrowly, on analyzing demand-side shocks, including the multiplier effects of the expenditure composition of road projects and programs. However, the sine qua non for road projects and programs is to reduce supply-side barriers in the form of travel time and road user costs. The fixed-price multiplier model does not capture these key transmission mechanisms. Furthermore, the multiplier model framework is a static framework. Accordingly, it does not capture the important dynamic effects of road projects and programs. In general, the multiplier model is fundamentally flawed in relation to impact evaluation of road projects and programs.[13]

Finally, the long-standing aid effectiveness literature have attempted to assess the overall impact of aggregate aid-financed project and program costs since the early 1970s – for an overview, see Hansen & Tarp (2000) – including aid-financed infrastructure projects and programs. This literature has had special priority to (unilateral and multilateral) donor organizations and recipient countries, since they need impact evaluation studies to support decision making and justify their decisions to their polity. The recent aid effectiveness literature is based on panel data growth regressions at the country-wide level (Boone 1996,

[12] The main exception is large primary road and highway projects, which affects long road segments with high traffic intensities.

[13] Studies of the employment impact of road projects which have focused on the fixed-price general equilibrium multiplier model methodology (in the ILO tradition) include McCord & van Seventer (2004). Other multiplier studies are surveyed in OECD (2002).

Burnside & Dollar 2000, Hansen & Tarp 2001, Guillaumont & Chavet 2001, Collier & Dollar 2002, Dalgaard, Hansen & Tarp 2004). The macro-econometric approach, in this literature, relies on the assumption that the impact of aid can be captured by a parsimonious reduced form specification, across the wide spectrum of developing countries and the wide spectrum of development projects and programs. Nevertheless, the econometric results have turned out to be very sensitive to the choice of sample and functional specification, suggesting that the macroeconomic impact of foreign aid is affected by country-specific characteristics which are not captured by the parsimonious specifications and/or the composition and allocation of country-specific aid inflows (Easterly, Levine & Roodman 2004, Roodman 2007). The results in the current paper suggest that there is strong project-specific variation in the benefits from capital road works (due to variation in e.g. traffic intensity, initial road quality measured by roughness level and strength of structural foundation, road surface type) and in the (non-linear) cost of capital road works (due to variation in e.g. overlay thickness). This point to the need for separate analyzes of aid effectiveness across the wide spectrum of developing countries and the wide spectrum of aid-financed (road and highway) projects and programs.

3. The CGE-RONET model

This section presents the CGE-RONET model framework. In general, the CGE-RONET model framework may be characterized as a dynamically-recursive CGE model with a transport satellite model. First, the transport model is used to simulate road degradation and vehicle operating costs over the 15 year lifetime of the road project. Second, the time paths of costs (including maintenance and reconstruction costs), and benefits (voc savings) are imposed on the dynamically-recursive CGE model in order to measure the lifetime net benefits of the road project. In the current paper, lifetime net benefits are calculated as the net present value (NPV) of value added, household welfare, and poverty gap, as well as the increase in work-years (simple summation of employment benefits over the 15 year road lifetime) and the reduction in poverty years (simple summation of poverty headcount reduction over the 15 year road lifetime).

The model framework is set up for two types of analyses. The first type of analysis measures the impact of current capital road works. For this type of analysis, the socioeconomic outcome of one road project (excluding current capital road works, but including future capital road works) is used as a counterfactual for measuring the net lifetime benefits of another road project (including both current and future capital road works). The second type of analysis measures the marginal impact of an increase in the minimum road quality of future capital road works strategies (defined by a maximum IRI roughness level over the 15 year time horizon). For this type of analysis, the socioeconomic outcome of one future capital road works strategy with a low minimum road quality level (defined by a high maximum IRI roughness level) is used as counterfactual for measuring the impact of another future capital road works strategy with a higher minimum road quality (defined by a lower maximum IRI roughness level). The current study will only focus on impact evaluation of current capital road works.

Specifically, the current model framework combines a dynamically-recursive Computable General Equilibrium (CGE) model of the 1-2-3 model type with marketing margins (Arndt, Jensen, Robinson & Tarp, 2000; Lofgren, Harris & Robinson, 2002), with the RONET partial equilibrium model (Archondo-Callao 2009).[14] The RONET model has been developed as a management tool for road sector programs in developing countries, and it focuses on measuring the net present value of a number of economic outcome variables including vehicle operating cost (voc) savings. In particular, the modeling of the time dimension

[14] The functional specifications of the RONET model have been derived from the HDM-4 model (PIARC 2005), while road user costs and the cost of capital road works (typically) are derived from the World Bank's RUCKS (Roads User Costs Knowledge) System (World Bank 2007a), and the World Bank's ROCKS (Road Costs Knowledge) System (World Bank 2007b).

allows the RONET model to obtain partial equilibrium measures of the lifetime benefits of road sector programs. The current approach extends the RONET model framework by modeling static and dynamic general equilibrium effects, which are associated with road projects and programs.[15]

3.1. The CGE model

The analyses in this study are based on a dynamically-recursive Computable General Equilibrium (CGE) model of the 1-2-3 model type with marketing margins. The model framework is based on a static CGE model of the 1-2-3 type (Arndt, Jensen, Robinson & Tarp, 2000; Lofgren, Harris & Robinson, 2002). To allow for measuring dynamic effects, the static model is transformed into a dynamically-recursive CGE model, by adding equations for updating of labor and capital factor stocks. The underlying static model is characterized by employing a constant elasticity of substitution (CES) specification for production functions, and a linear expenditure system (LES) specification for household consumption demand. On the trade side, imperfect substitution between domestic production and imports are modeled through the use of a CES specification (the Armington assumption), while imperfect transformation of domestic production into export goods is modeled through the use of a constant elasticity of transformation (CET) specification.[16]

The closure of the static CGE model includes flexible labor factor supplies and fixed relative labor factor prices (labor factor market closure), fixed capital factor supply and flexible relative capital factor prices (capital factor market closure), fixed government consumption as a share of absorption, fixed real government transfers, and flexible government savings (government budget closure)[17], fixed non-government institutional savings rates and flexible investment (savings-driven investment closure), and fixed foreign savings inflows combined with a flexible real exchange rate (external closure). In addition, flexible relative goods prices are allowed to clear the goods market (goods market closure). While relative prices are used to clear (most) markets, the absolute price level is not determined within the model

[15] In fact, the integrated CGE-RONET framework uses key functional specifications from the RONET model to develop a slightly modified framework for evaluating vehicle operating cost savings associated with specific *road projects*. The slight modification, whereby the cost and layer thickness of periodic maintenance are allowed to be endogenous, ensures that the integrated framework is given sufficient flexibility to evaluate *current capital road works* (with pre-determined future sequences of capital road works) and *future capital road works strategies* (with pre-determined minimum road quality levels), in contrast to the RONET model which evaluates *road programs* for entire road network strategies based on restrictive assumptions regarding the timing of future capital road works. The integrated CGE-RONET framework can easily be adapted to evaluate *road programs* for entire road networks.

[16] Uniform agricultural and non-agricultural trade elasticities of 1.5 were imposed on the model framework, as part of the model calibration.

[17] The counterfactual projection of the Ghanaian economy over the 15 year projection horizon, employed in this study, is based on fixed government consumption as a share of absorption. The counterfactual government spending pattern is, subsequently, imposed on the model (with adjustment for increased capital road works costs) in the simulations of road projects.

framework. The model therefore specifies the household consumer price index for marketed goods as a price numeraire.

The current closure differ from “the standard neoclassical closure”, since relative prices do not clear all markets. In particular, the labor market closure relies on quantity adjustment in labor markets, while the relative prices of labor are fixed. The current closure is, therefore, a so-called “structural closure”. The non-standard labor market closure was chosen because underemployment is considered to be widespread in Ghana. In addition, the specification of available labor market resources means that the framework can be used to analyze the employment (demand) effects of road projects.

3.2. The transport model

The RONET model framework (Archondo-Callao 2009) is a partial equilibrium simulation methodology for impact evaluation of road network programs. It has evolved from the engineering tradition for impact evaluation, and, as such, it is focused on measuring lifetime benefits of road and highway programs. The RONET model framework has been developed, within the World Bank, on the basis of the HDM-4 model framework (PIARC 2005).[18] The RONET model computes a number of outcome variables which are of direct interest to road sector management, including road user charges, funding requirements, fuel consumption revenues, and road user revenues. The key measure of (road user) benefits, in the RONET model, is vehicle operating cost (voc) savings associated with capital road works.

The RONET model focuses, narrowly, on estimating voc savings, without any attempt at estimating the general equilibrium effects which follows from these voc savings. However, the voc savings can be used to measure the implied transportation activity productivity gain from capital road works. Accordingly, the transport model, underlying the current study, is used to capture the following link:

Capital road works cost sequence (over 15 year time horizon)

↓

Road degradation and roughness progression sequence (over 15 year time horizon)

↓

Vehicle operating cost savings sequence (over 15 year time horizon)

↓

Transportation activity productivity gains sequence (over 15 year time horizon)

[18] The HDM-4 model framework builds on previous model versions (HDM-1, HDM-2 & HDM-3), which were developed within the World Bank. The development of the HDM-4 model framework was initiated by the World Bank, but the project has been managed by the World Road Association (PIARC) since 1996.

The key concept of the transport model is the so-called "International Roughness Index" (IRI, m/km).[19] The transport model includes a so-called roughness progression model (for paved roads), where the progression of the roughness index depends on the age of the road surface since last capital road works, and on the strength of the structural foundation measured by a structural number (SNC).[20] In addition, the transport model includes a specification for the reduction in the roughness index and increase in the structural number following each instance of capital road works, including periodic maintenance and re-construction. A predetermined capital road works sequence will, therefore, allow for the derivation of a roughness progression sequence (over the road lifetime/simulation period, in this case 15 years).

Furthermore, the transport model includes a structural cubic relationship, where unit vehicle operating costs (US$/vehicle-km) can be derived from the underlying roughness index.[21] Subsequently, total vehicle operating costs (for the road section in focus) can be derived by multiplying the unit vehicle operating cost with (1) the road length, and (2) the traffic-intensity. The sequence of vehicle operating cost savings is a clean measure of the sequence of productivity gains in the transportation activity, i.e. it measures the reduction in transport sector production costs associated with an unchanged supply of transportation services. The dynamic sequence of relative transportation activity TFP gains (in percentage terms) may, therefore, be derived, for the entire 15 year time horizon, by comparing the vehicle operating cost savings, for a given year, to the counterfactual value of total transport sector costs, for that same year. The counterfactual dynamic sequence of total transport sector costs is derived from the CGE model framework.

The current transport model includes a few modifications compared to the underlying RONET model framework. These modifications are implemented in order to capture changes in road quality over time, due to road degradation and political strategies. One of the main points of this paper is that road quality changes over time, and that an understanding of these dynamic road quality changes is essential for evaluating the impact of capital road works. In this paper, the term "road quality" will be identified with the IRI roughness level of the road. Hence, road quality is understood to be good when the IRI roughness level is low (e.g. < 4.5 m/km), while road quality is understood to be poor when the IRI roughness level is high (e.g. > 6.0 m/km).

[19] The IRI roughness index is a continuous index variable which is, normally, assumed to vary between 1-25 (m/km). For paved road surface types, road quality levels may, roughly, be categorized (according to the IRI roughness level) as very good (1-3 m/km), good (3-4.5 m/km), fair (4.5-6.0 m/km), poor (6.0-11.0 m/km) and very poor (11.0-16.0 m/km) (Archondo-Callao 2009).

[20] The SNC structural number, which measures the strength of the structural foundation, is a continuous variable which, typically, vary between 1.5-8.0 (Archondo-Callao 2009).

[21] The parameterization of the cubic polynomial for unit vehicle operating costs vary with the traffic intensity (and traffic composition) of the road section in focus. The current transport model distinguishes between nine different levels of traffic intensity (and traffic composition).

The RONET model relies on a specific sequence of capital road works (for each part of the entire road network), where each instance of periodic maintenance, in the form of overlays, is defined in terms of a specific “overlay thickness” (mm).[22] The exogenous specification of “overlay thickness” levels implies that ex post road quality levels (IRI roughness levels after periodic maintenance) are endogenous. The current transport model differs from the RONET specification in the sense that it specifies ex post target road quality levels as exogenous (defined by an ex post “target IRI roughness” level after periodic maintenance), while “overlay thickness” levels are allowed to be endogenous.[23] Since the cost of periodic maintenance vary with the “overlay thickness”, the specification of endogenous “overlay thickness” levels implies that periodic maintenance costs needs to be endogenous as well. Accordingly, quadratic polynomials were specified to capture the functional relationship between “overlay thickness” and “two-lane unit costs of road works” for each road surface type.[24]

The cost of periodic maintenance (in a given year) is calculated by multiplying the endogenous “two-lane unit cost” by the length of the road section (km) and the number of lanes (divided by 2). Similarly, the cost of re-construction (in a given year) is calculated by multiplying an exogenously given “two-lane unit cost” by the length of the road section (km) and the number of lanes (divided by 2). The total net present value (NPV) of the (dynamic sequence of) road project costs is, subsequently, calculated by adding current and (discounted) future capital road works costs.[25] In relation to the CGE model simulations, the dynamic sequence of road project costs is added, period by period, to government consumption. The total NPV value of road project costs is, subsequently, used as the basis for calculating socioeconomic multipliers.

The modifications to the RONET transport model, although minimal, are essential for the analyses of this paper. The analyses are, fundamentally, focused on capturing the importance of the variation in road quality over time. In particular, the transport model framework is aimed at capturing the importance of the (politically determined) quality of capital road works, and, more generally, of the impact of future capital road works strategies based on (politically determined) minimum road quality considerations. The two

[22] The overlay thickness associated with periodic maintenance of roads, typically, varies between 0-80 mm (Archondo-Callao 2009). The overlay thickness is an important determinant of both the level and progression of roughness. In typical transport models, overlay thickness affects the progression of roughness, since it affects the structural number. The RONET model (and the current study) abstracts from the latter transmission mechanism. Instead, it focuses, narrowly, on the impact of overlay thickness on the level of roughness.

[23] Re-construction of roads leads to a road quality level (IRI level associated with re-construction) which may differ from the ex post (target) road quality level associated with periodic maintenance.

[24] Quadratic polynomials were chosen as the preferred functional form, since unit costs for periodic maintenance (US$/km) increases with the “overlay thickness” (mm). Furthermore, unit costs for road works differ between road surface types. Accordingly, the parameterization of the quadratic polynomial for unit road works costs varies between cement/concrete, asphalt mix, and surface treatment pavement types.

[25] A discount rate of 12 percent is used for all net present calculations in this study.

types of analyses are both, fundamentally, analyses of the importance of policy decisions on road quality levels (as a response to natural road quality changes due to road degradation). The evaluation of the impact of current capital road works relies, fundamentally, on the specification of the future sequence of capital road works (and the quality of these road works measured by the ex post IRI roughness level). Similarly, the evaluation of the impact of future capital road works strategies relies, fundamentally, on the specification of an ex post IRI roughness level (which defines the quality of capital road works) as well as the specification of an ex ante maximum IRI roughness level (which defines the minimum quality of the road over the 15 year time horizon). The current study will only focus on impact evaluation of current capital road works.

4. Calibration of the CGE-RONET model for Ghana

This section presents the Ghana data sets which are used for model calibration, and outlines the parameterization and structural characteristics of the CGE-RONET model framework for Ghana.

4.1. Calibration of the CGE model

The CGE model framework was calibrated on the basis of an aggregate five sector version of a recently developed 2004 Ghana SAM (Jensen, van den Andel & Duncan 2008). [26] The five sectors include agriculture (including forestry & fishery), industry (including manufacturing, construction & mineral extraction), trade services, transportation services, and other services. The aggregation was undertaken to facilitate analysis and reduce the amount of detail. In addition, the SAM retains one marketing margin account, 22 primary factors of production including 21 labor factor accounts and one capital factor account, one enterprise sector, 21 household groups, one current government budget account and one rest of the world account (current account of the balance of payments). The four original capital accounts (including investment/stock changes in private/government sectors) were aggregated into one aggregate capital account including stock changes and investment expenditures.

Table 1. Supply and Demand Structure of the Ghana Economy (percent)

	Value Added	Exports	Imports	E/X	M/Q	Domestic Margin Rate
Agriculture, Forestry & Fishery	27.9%	30.4%	2.7%	20.1%	3.6%	15.3%
Industry	27.5%	52.9%	87.5%	19.9%	41.2%	11.2%
Trade services	11.3%	0.0%	0.0%	0.0%	0.0%	0.0%
Transportation services	9.7%	0.8%	0.1%	1.3%	0.2%	0.0%
Other Services	23.5%	15.9%	9.8%	10.6%	9.4%	0.0%
Total / Average	100.0%	100.0%	100.0%	13.9%	21.9%	5.8%

Source: 2004 Ghana SAM (Jensen, van den Andel & Duncan; 2008).

Note: E – Exports; M – Imports; X – Domestic Production; Q – Domestic Supply.

The supply and demand structure of the Ghanaian economy is displayed in Table 1. In terms of value added generation, the economy is divided equally among four economic sectors: agriculture (28% of GDP), industry (28% of GDP), trade and transportation services (21% of GDP), and other services (23% of GDP).

[26] The 2004 Ghana SAM was developed on the basis of a newly developed 2004 Ghana Supply-Use Table (van den Andel 2007a, 2007b), and contains 139 production activity accounts, 175 commodity accounts, 22 factor accounts, 21 household accounts, and 21 home consumption accounts (Jensen, van den Andel & Duncan 2008). A key implication of this work was that 2004 GDP per capita amounted to 758 USD in nominal USD terms and to 1,860 PPP-USD in PPP-corrected terms. This raises the average Ghanaian income level by around 90 percent above previous (unofficial) IMF estimates, and places Ghana ahead of many neighboring countries, including Benin and Cote d'Ivoire.

International trade is concentrated in industrial goods, accounting for around 55 percent of exports and 90 percent of imports. International trade in agricultural goods accounts for an additional 30 percent of exports, while trade in services account for the remaining 15 percent of exports and 10 percent of imports. International trade shares, which are important determinants of trade flows in the CGE model, reflect the general trade pattern. Accordingly, trade shares are relatively high for the industry sector (exports: 20%; imports: 40%), and relatively small for the agriculture sector (exports: 20%) and the service sector (exports: 10%; imports: 10%).

The underlying SAM data set includes one marketing margin account. For the purposes of model implementation, the marketing margin account was disaggregated into separate marketing margin accounts for imports, exports, and domestically marketed production, assuming that margin rates are similar between the three goods categories. Domestic margin rates are presented in Table 1, and they indicate that agricultural margin rates are relatively high (15 percent) compared to industrial margin rates (11 percent). Service sectors do not incur marketing costs per definition. Compared to the overall average (6 percent), agricultural marketing margin rates are very high. Reductions in marketing margins (including trade and transportation costs) are therefore particularly important for the development of the agricultural sector and for employment in rural areas of Ghana.

The production structure of the Ghanaian economy is presented in Table 2. The agricultural production sector is characterized by a very low intermediate input cost share (12 percent) and a very high primary factor cost share (89 percent). This is typical for a low-income country like Ghana, where a large part of agricultural production is dominated by traditional production methods. However, the numbers also indicate that the agricultural sector is the most capital-intensive production sector in Ghana, with a 67 percent capital cost share. This, supposedly, reflects high returns to land.

Table 2. Production Structure of the Ghana Economy (percent)

	Agriculture, Forestry & Fishery	Industry	Trade	Transport	Other Services
Intermediate Inputs	**12.3%**	**59.3%**	**15.9%**	**39.2%**	**37.4%**
Labor	**22.1%**	**12.1%**	**36.4%**	**19.2%**	**29.1%**
Low Skill Labor	14.3%	3.6%	13.6%	3.7%	3.1%
Medium Skill Labor	6.2%	4.2%	15.4%	13.3%	7.0%
High Skill Labor	1.7%	4.3%	7.4%	2.2%	19.1%
Capital	**66.8%**	**34.1%**	**31.3%**	**41.6%**	**33.5%**
Production Tax/Subsidy	**-1.2%**	**-5.5%**	**16.4%**	**0.0%**	**0.0%**
Total / Average	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: 2004 Ghana SAM (Jensen, van den Andel & Duncan; 2008)

In contrast, industrial production is characterized by a relatively high intermediate input cost share (59 percent) and a relatively low primary factor cost share (46 percent). In addition, industrial production is characterized by a relatively low capital cost share (34 percent). Nevertheless, the relatively strong capital-intensity of industrial production is reflected in the ratio between capital and labor costs (2.8). Accordingly, the relative capital-to-labor factor cost ratio of industrial production is, by far, the highest among non-agricultural production sectors.

Among the three service sectors, the transport sector is, by far, the most capital-intensive. It has the highest capital cost share (42 percent), and it has the highest capital-to-labor factor cost ratio (2.2). This feature of the Ghana economy is going to be particularly important for assessing the impact of road projects. The reduced need for transportation services, due to road project induced increases in transport sector productivity, implies that road projects will allow capital to be released from the transport sector. Subsequently, the released capital can be put to productive use in other labor-intensive production sectors, and help raise income and employment levels in the Ghanaian economy.

Table 2 also shows that skill intensities in labor employment differ strongly between production sectors. Agricultural production has a relatively high cost share for low skill labor (14 percent) and the production of other services has a relatively high cost share for high skill labor (19 percent), while industrial production has similar cost shares for low, medium and high skill labor (4 percent). The transportation activity employs mainly medium skill labor. Accordingly, the production of transportation services has a high cost share for medium skill labor (13 percent), and relatively low cost shares for low skill labor (4 percent) and high skill labor (2 percent). These labor market features are important, for the determination of the distribution of the potential employment gains from road projects. Accordingly, reduced input needs in the production of transportation services is likely to hurt medium skilled employment, while the income-induced increased demand for other goods and services is likely to benefit low and high skill employment.

While the static CGE model is calibrated on the basis of the 2004 Ghana SAM, the parameterization of the dynamic equations for updating of factor stocks are based on the Maquette for MDG Simulations (MAMS) model – a dynamically-recursive model of the 1-2-3 type, which has been implemented for Ghana by World Bank (2007c) and documented by Löfgren & Diaz-Bonilla (2008).[27] Due to the labor market closure with flexible labor factor supplies, the capital accumulation equation is the only (dynamic) equation which is parameterized on the basis of data from the Ghana MAMS model.

[27] This model was calibrated on the basis of a 2005 Ghana SAM database, which relied (partly) on the 1993 Supply-Use Table for Ghana. In contrast, the current model relies on a 2004 SAM database which was constructed on the basis of a recently developed 2004 Supply-Use Table.

4.2. Parameterization of the transport model

The transport model, used in this study, is parameterized on the basis of data from a 2005 Ghana RONET model (MoT 2008).[28] This includes the traffic composition of roads with nine different levels of traffic intensity (and derived annual number of equivalent standard axles), the parameterization of the cubic polynomials for unit vehicle operating costs for road users (which vary with the nine different levels of traffic intensity and traffic composition), the parameterization of the road degradation equations, and the establishment of unit re-construction costs (US$/km) for each of the three (paved road) surface types including Cement/Concrete, Asphalt Mix, and Surface Treatment. In addition, quadratic polynomials for periodic maintenance unit costs (US$/km), as a function of the overlay thickness (mm), were calibrated for each of the three (paved road) surface types.[29]

[28] The SAM database, underlying the CGE model, reflects the economic structure of Ghana in 2004, while the database, underlying the Ghana RONET model, reflects structural characteristics of the Ghana transport sector for 2005. Accordingly, the current model specification relies on the assumption that unit costs and unit benefits have remained unchanged, in Ghana, between 2004 and 2005.

[29] Two pairs of (unit road cost, overlay thickness) observations were available for each (paved road) surface type including Cement/Concrete, Asphalt Mix, and Surface Treatment (MoT 2008). Hence, the quadratic polynomials were calibrated on the basis of these observations and the assumption of a zero intercept, i.e. that zero overlay thickness is reflected in zero unit road costs.

Table 5. Summary characteristics of road section

Road characteristic	Value
Road Type	Primary
Road Surface	Asphalt Mix
Length of road segment (km)	100
Average Annual Daily Traffic (cars/day)	20,000
Number of Lanes	2
Time period since last rehabilitation (years)	5
Initial structural number (SNC)	3.0
Initial IRI roughness of road segment (m/km)	5.1

5. Impact evaluation of current capital road works

In this section, we will apply the CGE-RONET model to evaluate the economic impact of a specific road section in Ghana. The road section is a 100km segment of a 2-lane primary road with asphalt mix pavement and average annual daily traffic of 20,000 vehicles.[30] The initial pavement age (time since last capital road work) is set at 5 years, the initial strength of the structural foundation, i.e. structural number (SNC), is set at 3.0, and the initial IRI roughness level is set at 5.1 m/km. A summary of the characteristics of the road section is provided in Table 5. [31]

The simulations will focus on impact evaluation of current capital road works (period 0) for the road section under consideration. All simulations will cover the initial year (period 0) and a 15 year time horizon (period 1-15). A 15 year time horizon was chosen to cover the lifetime of current capital road works (implemented in period 0), and thereby allow for lifetime net benefit calculations. As will be demonstrated below, the impact of current capital road works depends, crucially, on the future sequence of capital road works. Accordingly, in order to make a proper impact evaluation of current capital road works, it is necessary to specify the planned sequence of future capital road works associated with the road section under consideration. Table 6 outlines six road project sequences for future capital road works, including no future capital road works (PRJ0) and between 1-5 future capital road works, equally spaced in time (PRJ1-PRJ5). For each project (PRJ0-PRJ5), two simulations are undertaken including a simulation with current capital road works (SIM1), and a simulation without current capital road works (SIM0). In each case, the second simulation works as the counterfactual for the former simulation.

[30] The current Ghana model framework allows for impact evaluation of various road types (primary, secondary, tertiary, and urban roads), as well as various pavement types (cement/concrete, asphalt mix, and surface treatment). In the following analyses, focus will be on a primary road segment with asphalt mix pavement. Nevertheless, the qualitative results carry over to other road and pavement types.

[31] An additional assumption is made in relation to the (otherwise) policy-determined “target road quality” (IRI value after capital road works) which is used to determine the necessary “overlay thickness” in relation to periodic maintenance. This target IRI value was chosen to be 3.0 (corresponding to a very good road quality).

Table 6. Timing of capital road works (Fixed timing of planned future sequence)

	Projects (PRJ0-PRJ5) with Simulation (SIM1) & Counterfactual (SIM0)											
Time Period	**PRJ0**		**PRJ1**		**PRJ2**		**PRJ3**		**PRJ4**		**PRG5**	
	SIM1	**SIM0**	**SIM1**	**SIM0**	**SIM1**	**SIM0**	**SIM1**	**SIM0**	**SIM1**	**SIM0**	**SIM1**	**SIM0**
T00	•		•		•		•		•		•	
T01												
T02											•	•
T03									•	•		
T04							•	•				
T05					•	•					•	•
T06									•	•		
T07			•	•							•	•
T08							•	•				
T09									•	•		
T10					•	•					•	•
T11												
T12							•	•	•	•	•	•
T13												
T14												
T15												
# Current Road Works	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**
# Future Road Works	**0**	**0**	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**

The costs of capital road works are presented in Table 7. All capital road works costs are expressed in net present value terms, i.e. discounted by a 12 percent discount rate. Moreover, all costs refer to periodic maintenance (overlay), except for the single capital road work in the counterfactual simulation SIM0 of road project PRJ1, which refers to re-construction.[32] The numbers indicate that current capital road works reduces the cost of future capital road works. Accordingly, while the gross cost of current capital road works is 10.6 mio. GHC, the net cost of adding current capital road works to an existing strategy of future capital road works varies between 3.3 mio. GHC (PRJ1) and 8.5 mio. GHC (PRJ2). On the one hand, the very low net cost of current capital road works under road project PRJ1 (3.3 mio. GHC) follows since the long postponement of necessary capital road works, under the counterfactual, means that expensive re-construction becomes necessary. On the other hand, the relatively high net cost of current maintenance under road project PRJ2 (8.5 mio. GHC) follows since the increase in future capital road costs, under the counterfactual, is eroded by the relatively low time value of future costs (due to discounting).

The vehicle operating cost (voc) savings, associated with current and future capital road works, are presented in Table 8. The numbers indicate that net gains are positive for all road projects, and that there

[32] Re-construction of the road is necessary when road degradation, measured by the IRI roughness level, reaches a certain predefined level. In the case of an Asphalt mix road, re-construction is deemed necessary when the IRI roughness level exceeds 10.5, implying that the asphalt mix road is in very poor condition (Archondo-Callao 2009).

are significant net gains to be reaped in each case, whether or not current capital road works are undertaken. Multipliers vary between 22.7-22.8 (SIM1 of road projects PRJ4-PRJ5) and 36.4 (SIM0 of road project PRJ2). Accordingly, the highest net gains per GHC spent on (current and future) capital road works, occurs for the road project with no current and two future capital road works, while the lowest net gains per GHC spent on (current and future) capital road works occurs for the road projects with current road works and 4-5 future road works.

The voc savings, which can be attributed, more narrowly, to current capital road works, are presented in Table 9. The voc savings are positive for all projects. Accordingly, for the road section under investigation, current capital road works leads to positive lifetime voc savings, under every alternative sequence of future capital road works, with at least 5 capital road works which are equally spaced in time. However, the numbers also indicate that the gain to current capital road works differ, strongly, between the different road projects. There seems to exist a strong inverse relationship between the return to current capital road works and the number of future capital road works. Current capital road works multipliers vary between 34.4 (road project PRJ0 with zero future capital road works) and 5.5 (road project PRJ5 with five future capital road works). The only exception to a monotone inverse relationship is road project PRJ1, where the multiplier is 51.0. The reason for the high current capital road works multiplier under road project PRJ1 is, as noted above, the very low net cost of current capital road works, which follows from the need for expensive re-construction under the counterfactual without current capital road works.

Total real GDP gains from both current and future capital road works are presented in Table 10. The numbers indicate that the real GDP gains are always positive, and they are approximately twice as high as voc savings. This indicates that spillover effects account for almost half of the lifetime benefits of road projects (for the road section under investigation). Furthermore, the numbers indicate that dynamic effects account for more than 95 percent of the lifetime real GDP gains (when lifetime gains are compared to the gains from period T00). This indicates that it is crucial to account for both dynamic effects and spillover effects when evaluating capital road works.

Real GDP multipliers of current and future capital road works vary between 41.9-68.1. Interestingly, the overall ranking of projects changes, when the outcome variable is changed from voc savings to real GDP gains. Accordingly, the highest real GDP gains per GHC spent on current and future capital road works, occurs for the road project with current capital road works and no future capital road works, while the highest voc savings per GHC spent on current and future capital road works, occurs for the road project with no current capital road works and two future capital road works. This result suggests that dynamic effects and spillover effects may be important for the ranking of road projects.

Table 7. Capital road works costs in NPV terms (mio. GHC)

	Project Simulation (SIM1) & counterfactual (SIM0)											
Time Period	PRJ0		PRJ1		PRJ2		PRJ3		PRJ4		PRJ5	
	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0
T00	10.6	0	10.6	0	10.6	0	10.6	0	10.6	0	10.6	0
T01	0	0	0	0	0	0	0	0	0	0	0	0
T02	0	0	0	0	0	0	0	0	0	0	4.6	10.0
T03	0	0	0	0	0	0	0	0	5.8	9.3	0	0
T04	0	0	0	0	0	0	6.1	8.5	0	0	0	0
T05	0	0	0	0	6.0	7.8	0	0	0	0	3.8	4.2
T06	0	0	0	0	0	0	0	0	3.1	3.6	0	0
T07	0	0	5.4	12.7 [1]	0	0	0	0	0	0	1.3	1.5
T08	0	0	0	0	0	0	3.0	3.5	0	0	0	0
T09	0	0	0	0	0	0	0	0	1.8	2.0	0	0
T10	0	0	0	0	2.7	3.1	0	0	0	0	1.6	1.7
T11	0	0	0	0	0	0	0	0	0	0	0	0
T12	0	0	0	0	0	0	1.6	1.8	1.1	1.2	0.5	0.5
T13	0	0	0	0	0	0	0	0	0	0	0	0
T14	0	0	0	0	0	0	0	0	0	0	0	0
T15	0	0	0	0	0	0	0	0	0	0	0	0
Total Costs	10.6	0.0	16.0	12.7	19.4	10.9	21.3	13.8	22.4	16.2	22.4	17.9
# Road Works	1	0	2	1	3	2	4	3	5	4	6	5

Source: own calculations based on a 12 percent discount rate; [1] Reconstruction cost.

Table 8. Vehicle operating cost savings (mio. GHC)

	Program simulation (SIM1) & counterfactual (SIM0)											
Time Period	PRJ0		PRJ1		PRJ2		PRJ3		PRJ4		PRJ5	
	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0
T00	12.7	0	12.7	0	12.7	0	12.7	0	12.7	0	12.7	0
T01	16.0	0	16.0	0	16.0	0	16.0	0	16.0	0	16.0	0
T02	19.2	0	19.2	0	19.2	0	19.2	0	19.2	0	22.4	22.4
T03	22.3	0	22.3	0	22.3	0	22.3	0	26.9	26.9	25.9	25.8
T04	25.1	0	25.1	0	25.1	0	31.1	31.1	30.3	30.1	29.2	28.9
T05	27.5	0	27.5	0	34.8	34.8	34.1	34.0	33.3	32.9	34.8	34.8
T06	29.6	0	29.6	0	37.5	37.3	36.8	36.4	38.0	38.0	37.5	37.5
T07	31.3	0	40.7	42.5	39.7	39.3	39.0	38.4	40.3	40.2	40.7	40.7
T08	32.4	0	42.5	43.4	41.4	40.9	42.9	42.9	42.0	41.9	42.5	42.5
T09	33.1	0	43.6	43.6	42.5	41.8	44.1	44.1	44.4	44.4	43.7	43.6
T10	32.7	0	43.6	42.5	44.8	44.8	44.2	44.1	44.5	44.5	44.8	44.8
T11	27.3	0	38.5	36.3	39.7	39.7	39.1	39.0	39.4	39.4	39.7	39.7
T12	22.4	0	34.0	30.6	35.2	35.2	35.7	35.7	35.7	35.7	35.7	35.7
T13	18.2	0	29.9	25.4	31.2	31.1	31.7	31.7	31.7	31.7	31.7	31.7
T14	14.4	0	26.3	20.7	27.6	27.5	28.1	28.1	28.1	28.1	28.1	28.1
T15	11.2	0	23.0	16.5	24.4	24.3	24.9	24.9	24.9	24.9	24.9	24.9
Total Gains	375.5	0.0	474.7	301.5	494.2	396.5	501.9	430.1	507.6	458.8	510.3	481.0
Total Costs	10.6	0.0	16.0	12.7	19.4	10.9	21.3	13.8	22.4	16.2	22.4	17.9
Net Gains	364.9	0.0	458.7	288.8	474.8	385.7	480.6	416.3	485.2	442.6	487.9	463.1
Multipliers	35.4	-	29.7	23.8	25.5	36.4	23.6	31.2	22.7	28.4	22.8	26.9
# Road Works	1	0	2	1	3	2	4	3	5	4	6	5

Source: own calculations based on 12 percent discount rate; [1] Reconstruction cost.

Table 9. Vehicle operating cost savings from current capital road works (mio. GHC)

	Program					
Time Period	**PRJ0**	**PRJ1**	**PRJ2**	**PRJ3**	**PRJ4**	**PRJ5**
T00	**2.1**	**2.1**	**2.1**	**2.1**	**2.1**	**2.1**
T01	**16.0**	**16.0**	**16.0**	**16.0**	**16.0**	**16.0**
T02	**19.2**	**19.2**	**19.2**	**19.2**	**19.2**	**5.4**
T03	**22.3**	**22.3**	**22.3**	**22.3**	**3.5**	**0.1**
T04	**25.1**	**25.1**	**25.1**	**2.4**	**0.2**	**0.3**
T05	**27.5**	**27.5**	**1.7**	**0.2**	**0.4**	**0.4**
T06	**29.6**	**29.6**	**0.2**	**0.4**	**0.5**	**0.0**
T07	**31.3**	**5.6**	**0.4**	**0.5**	**0.1**	**0.2**
T08	**32.4**	**-0.9**	**0.5**	**0.5**	**0.1**	**0.0**
T09	**33.1**	**0.0**	**0.7**	**0.0**	**0.2**	**0.0**
T10	**32.7**	**1.1**	**0.4**	**0.1**	**0.0**	**0.1**
T11	**27.3**	**2.2**	**0.0**	**0.1**	**0.0**	**0.0**
T12	**22.4**	**3.4**	**0.1**	**0.2**	**0.1**	**0.0**
T13	**18.2**	**4.5**	**0.1**	**0.0**	**0.0**	**0.0**
T14	**14.4**	**5.6**	**0.1**	**0.0**	**0.0**	**0.0**
T15	**11.2**	**6.5**	**0.2**	**0.0**	**0.0**	**0.0**
Net Benefit (curr. maint.)	**364.9**	**169.8**	**89.1**	**64.2**	**42.6**	**24.7**
Net Cost (curr. maint.)	**10.6**	**3.3**	**8.5**	**7.5**	**6.2**	**4.5**
Multiplier	**34.4**	**51.0**	**10.5**	**8.5**	**6.8**	**5.5**

Source: own calculations. Note: Net present value calculations based on 12 percent discount rate.

The real GDP gains, which can be attributed, more narrowly, to current capital road works, are presented in Table 11. For the road section under investigation, current capital road works leads to positive real GDP gains under every alternative sequence of future capital road works (where capital road works are equally spaced in time). However, as was the case for voc savings, the return to current capital road works depend, strongly, on the future sequence of capital road works. Real GDP multipliers of current capital road works vary between 68.3 (road project PRJ0 with zero future capital road works) and 10.7 (road project PRJ5 with five future capital road works). Accordingly, there seems to be a strong inverse relationship between the return to current capital road works and the number of future capital road works.

The numbers also indicate that real GDP gains from current capital road works are approximately twice as high as voc savings, and that dynamic effects accounts for 59-97 percent of the lifetime real GDP gains from current capital road works (when lifetime gains are compared to the gains from period T00). This underlines that it is crucial to account for dynamic effects and spillover effects, as well as future sequences of capital road works, when evaluating current capital road works.

Table 10. Real GDP gains (mio. GHC)

	Simulation											
Time Period	PRJ0		PRJ1		PRJ2		PRJ3		PRJ4		PRJ5	
	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0	SIM1	SIM0
T00	19.9	0	19.9	0	19.9	0	19.9	0	19.9	0	19.9	0
T01	20.1	0	20.1	0	20.1	0	20.1	0	20.1	0	20.1	0
T02	26.4	0	26.4	0	26.4	0	26.4	0	26.4	0	31.7	34.0
T03	32.7	0	32.7	0	32.7	0	32.7	0	40.4	40.5	36.5	35.5
T04	38.9	0	38.9	0	38.9	0	48.7	46.6	44.7	42.6	43.8	42.6
T05	44.8	0	44.8	0	56.5	52.1	52.7	49.1	52.0	49.7	55.4	54.7
T06	50.3	0	50.3	0	60.3	54.8	59.8	56.0	62.6	60.9	60.5	59.5
T07	55.3	0	70.3	64.5	66.9	61.4	66.3	62.3	67.6	65.7	68.9	68.1
T08	59.7	0	73.4	62.8	72.9	67.3	76.1	73.0	73.7	71.8	74.3	73.4
T09	63.3	0	78.9	67.4	78.1	72.4	79.9	76.6	81.2	79.5	79.8	78.9
T10	65.3	0	82.5	69.8	85.5	80.9	83.6	80.4	84.0	82.2	85.3	84.5
T11	59.6	0	78.2	64.2	79.9	75.2	79.5	76.3	79.9	78.1	80.3	79.5
T12	54.2	0	74.2	58.6	76.1	71.5	77.4	74.6	77.3	75.7	77.2	76.4
T13	49.1	0	70.3	53.2	72.4	68.0	72.9	70.1	73.1	71.5	73.4	72.6
T14	44.4	0	66.7	47.9	68.9	64.6	69.5	66.8	69.7	68.1	69.9	69.1
T15	39.9	0	63.1	42.8	65.6	61.4	66.3	63.6	66.4	64.9	66.6	65.9
Total Gains	724.0	0.0	890.9	531.3	921.2	729.4	931.8	795.6	939.1	851.3	943.6	894.8
Total Costs	10.6	0.0	16.0	12.7	19.4	10.9	21.3	13.8	22.4	16.2	22.4	17.9
Multiplier	68.3	-	55.7	41.9	47.6	67.0	43.7	57.7	42.0	52.7	42.1	50.0
# Road Works	1	0	2	1	3	2	4	3	5	4	6	5

Source: own calculations. Note: Net present value calculations based on 12 percent discount rate.

Table 11. Real GDP gains from current capital road works (mio. GHC)

	Project					
Time Period	PRJ0	PRJ1	PRJ2	PRJ3	PRJ4	PRJ5
T00	19.9	19.9	19.9	19.9	19.9	19.9
T01	20.1	20.1	20.1	20.1	20.1	20.1
T02	26.4	26.4	26.4	26.4	26.4	-2.3
T03	32.7	32.7	32.7	32.7	-0.1	1.0
T04	38.9	38.9	38.9	2.1	2.1	1.1
T05	44.8	44.8	4.4	3.6	2.3	0.7
T06	50.3	50.3	5.5	3.8	1.6	0.9
T07	55.3	5.8	5.6	4.0	1.9	0.8
T08	59.7	10.6	5.7	3.0	2.0	0.9
T09	63.3	11.5	5.8	3.2	1.7	0.9
T10	65.3	12.7	4.6	3.2	1.8	0.8
T11	59.6	14.0	4.7	3.1	1.8	0.8
T12	54.2	15.5	4.6	2.8	1.6	0.8
T13	49.1	17.1	4.4	2.8	1.6	0.8
T14	44.4	18.7	4.3	2.7	1.6	0.8
T15	39.9	20.3	4.2	2.7	1.5	0.7
Net Benefit	724.0	359.6	191.8	136.2	87.8	48.8
Net Cost	10.6	3.3	8.5	7.5	6.2	4.5
Multiplier	68.3	108.0	22.6	18.1	14.1	10.7
Maximum IRI roughness	11.3	5.6	4.6	4.2	3.8	3.6

Source: own calculations. Note: Net present value calculations based on 12 percent discount rate.

Table 12. Socioeconomic gains from Current Capital Road Works (mio. GHC)

	Project					
Time Period	**PRJ0**	**PRJ1**	**PRJ2**	**PRJ3**	**PRJ4**	**PRJ5**
Real GDP (mio. GHC)	**724.0**	**359.6**	**191.8**	**136.2**	**87.8**	**48.8**
Poverty Gap (mio. GHC)	**-7.9**	**-3.9**	**-0.8**	**-0.5**	**-0.3**	**-0.1**
Employment (1000' work years)	**1,427.1**	**592.4**	**245.9**	**162.7**	**97.1**	**49.3**
Poverty Headcount (1000' poverty years)	**-778.0**	**-328.9**	**-144.2**	**-123.4**	**-52.2**	**-34.4**
Net Costs	**10.6**	**3.3**	**8.5**	**7.5**	**6.2**	**4.5**
Real GDP Multiplier	**68.3**	**108.0**	**22.6**	**18.1**	**14.1**	**10.7**
Poverty Gap Multiplier	**-0.7**	**-1.2**	**-0.1**	**-0.1**	**0.0**	**0.0**
Employment Multiplier (work year/GHC)	**0.135**	**0.178**	**0.029**	**0.022**	**0.016**	**0.011**
Poverty Headcount Multiplier (poverty year/GHC)	**-0.073**	**-0.099**	**-0.017**	**-0.016**	**-0.008**	**-0.008**
Maximum IRI (SIM1)	**11.3**	**5.6**	**4.6**	**4.2**	**3.8**	**3.6**

Source: own calculations. Note: Net present value calculations based on 12 percent discount rate.

In addition, Table 11 indicates that the maximum IRI roughness level (over the 15 year time horizon) declines rapidly with increases in the number of future capital road works. The IRI roughness level reaches a maximum value of 11.3 without any capital road works. This corresponds to a very poor road condition. If one future capital road works is allowed for (PRJ1), the maximum IRI roughness level (over the 15 year time horizon) drops to 5.6. This corresponds to a fair road condition. Furthermore, if three future capital road works is undertaken, in addition to the current capital road works (PRJ3), the maximum IRI roughness level (over the 15 year time horizon) drops to 4.2. This corresponds to a good road condition. Hence, the road under investigation can be maintained in a good condition, over the 15 year time horizon, with one current and three future capital road works. On the other hand, the planned implementation of three future capital road works reduces the real GDP multiplier of current capital road works from 68.3 (PRJ0 with no future capital road works) to 18.1 (PRJ3 with three future capital road works). One interpretation of these results is that the real GDP impact of current capital road works is (correctly) estimated to be fairly small, when account is taken of policymaker's desire to maintain roads in (fairly) good condition over the lifetime of the current capital road works. Another interpretation is that there may be a trade-off between maintaining roads in (fairly) good condition, to the immediate pleasure of road users, and getting the most out of (scarce) transport sector program funds in e.g. Sub-Saharan African countries.

The impact of current capital road works on a broader set of socioeconomic outcome measures is summarized in Table 12. The outcome measures include the NPV of the changes in real GDP and poverty gap, and the simple sum of changes in employment years and poverty headcount years. These outcome measures are supplemented by the maximum IRI roughness level over the 15 year time horizon. Current capital road works leads to strong gains for all socioeconomic outcome measure, when there are no future capital road works (PRJ0). The gains include a real GDP expansion of 724 mio. GHC, a poverty gap reduction of 7.9 mio. GHC, an employment expansion of 1.4 mio. work years, and a poverty reduction of 780,000 poverty years. These gains amount to an annual real GDP expansion of 48.3 mio. GHC, an annual poverty gap reduction of 500,000 GHC, a permanent employment expansion of 95,000 workers, and a permanent reduction in the poverty headcount of 52,000 individuals.

Nevertheless, the results from each of the socioeconomic outcome measures confirm that the (strength of the) impact of current capital road works depends, crucially, on the future sequence of capital road works. With three capital road works (corresponding to a good minimum road quality over the 15 year time horizon), the gains correspond to an annual real GDP expansion of 9.1 mio. GHC, an annual poverty gap reduction of 30,000 GHC, a permanent employment expansion of 10,800 workers, and a permanent reduction in the poverty headcount of 8,200 individuals. Hence, the annual gains from current capital road works are considerably smaller, when account is taken of the desire to maintain roads in a good condition over the lifetime of the current capital road works.

Taking account of the variation in the net cost of undertaking current capital road works does not change the conclusions. The net cost of current capital road works declines with the number of future capital road works, since current capital works leads to savings on future capital road works. The multipliers in Table 12 indicate that the absolute reduction in socioeconomic outcomes (e.g. between PRJ0 and PRJ3) is partly compensated for by the reduced net cost of current capital road works. However, while the benefits decline by a factor of five, the net costs declines by 30 percent (between PRJ0 and PRJ3). Hence, taking account of the variation in net costs makes no difference for the qualitative results. The impact of current capital road works is considerably smaller, when account is taken of policymaker's future desire to maintain roads in a good condition.

In sum, the results indicates that socioeconomic spillover effects can be significant and account for more than half of the lifetime benefits of capital road works, and that dynamic effects may account for more than 95 percent of the socioeconomic effects. Moreover, there are, potentially, very high multipliers associated with current and future capital road works. But the results also indicate that the impact of current capital road works is strongly dependent on the planned sequence of future capital road works. For the road section under investigation (100km Asphalt Mix with 20,000 average annual daily traffic), real GDP may expand by 10.7-108.0 GHC (in NPV terms over a 15 year time horizon) for each 1 GHC which is spent on current capital road works. In general, the return to current capital road works declines as the number of future capital road works increases. This suggests that the impact of current capital road works is (correctly) estimated to be fairly small, when account is taken of policymaker's future desire to maintain roads in good condition. On the other hand, it also indicates that the return to current capital road works in (low-income)

Sub-Saharan African countries may be substantial, given the limited availability of funds for future capital road works.

6. Conclusion

The simulation literature in the economics tradition, with its focus on general equilibrium models, is well suited for capturing (pecuniary) spillover effects from road and highway projects. The construction and maintenance of roads and highways allows drivers to reach their destinations in less time, trucks deliver goods to market in less time, and producers have lower costs in terms of gasoline, drivers' salaries, and depreciation of vehicles. These local benefits are, typically, the focus of the partial equilibrium methodologies in the engineering tradition. However, these "first order" effects perform another, equally important role, as the basis for the transmission of economic effects to the rest of the economy. In principle, the integration of the two methodologies, therefore, allows for measuring the "global benefits" from road and highway projects, including static (within-period) and dynamic (between-period) socioeconomic spillover effects.

The main purpose of this paper has been to develop a new general equilibrium simulation model framework, which can be used to make proper impact evaluation of capital road works for existing roads. This includes periodic maintenance and re-construction of roads. The new model framework has been developed, specifically, to take account of the important dynamic effects of capital road works. Dynamic effects of capital road works may extend over the very long term (>15 years). Hence, it is crucial to focus on the calculation of lifetime net benefits, over the very long term, when evaluating current capital road works. Furthermore, the impact of current capital road works depends, fundamentally, on the planned sequence of future capital road works. Hence, the new model framework has been developed, explicitly, to take account of road degradation and politically-determined target road quality levels, in the evaluation of current capital road works.

It has been argued, in this paper, that the "first order" effect of capital road works on vehicle operating cost (VOC) savings is the main transmission mechanism of economic effects to the rest of the economy. This is especially so in low-income Sub-Saharan African countries with high levels of underemployment, where increased labor supply, due to reductions in travel time, is unlikely to affect production decisions. Accordingly, the CGE-RONET model framework, which has been developed in this paper, focuses, narrowly, on capturing the link between capital road works and road degradation (over time), and the impact of road degradation on vehicle operating cost (VOC) savings and transport sector productivity.

The explicit specification of the transmission mechanism between capital road works and socioeconomic outcomes, i.e. the measurement of future sequences of transport sector productivity gains, is a novel feature. Most previous studies assume that road infrastructure capital enters, directly, into production and cost functions for (transportation and non-transportation) production activities. The new specification in this study allows for capturing a number of static and dynamic socioeconomic (pecuniary) spillover effects, including (i) reduced relative transportation prices, (ii) reduced marketing margins, (iii) reallocation of (scarce) capital resources, (iv) increased accumulation of (scarce) capital resources, and (v) increased employment of underemployed labor resources. In particular, the CGE-RONET model framework allows for capturing the gains from reduced transportation costs and marketing margins for both consumers (reduced costs of final demand for transportation services) and producers (reduced costs of intermediate demand for transportation services and reduced marketing margins); And it allows for measuring lifetime net benefits, which takes account of the varying future impact of current capital road works (due to road degradation and planned future capital road works).

The results of the current study indicates that dynamic effects may account for more than 95 percent of the lifetime real GDP gains associated with current capital road works. Furthermore, socioeconomic spillover effects may account for half of the lifetime real GDP gains (the other half being accounted for by "first order" effects in the form of VOC savings). This underlines the need for employing an evaluation framework which takes account of both dynamic effects and socioeconomic spillover effects. The results of the current study also demonstrates that (politically-determined) minimum road quality levels and/or planned future sequences of capital road works has significant implications for the impact of current capital road works. For the chosen 100km road segment with 20,000 annual daily traffic intensity, asphalt mix pavement and poor initial roughness level, the value added generation from 1 GHC spending on current capital road works (over a 15 year horizon) range between 11 GHC and 108 GHC. These results indicate that the impact of current capital road works is highly dependent on the planned future sequence of capital road works. In particular, the results suggest that in low-income Sub-Saharan African countries, where resources for future capital road works are relatively small, the return to current capital road works may be 5-10 times as high as the return for similar countries with ample resources for future capital road works.

The CGE-RONET model framework is constructed with the purpose of analyzing capital road works for existing roads and highways. In this way, it is complementary to the large literature of, predominantly, regional simulation studies, which employs spatial CGE models to analyze the impact of new construction of roads and highways. Nevertheless, the current study indicates that these studies, which are, typically, based on static CGE models, needs to account, explicitly, for the time dimension, in order to capture important dynamic effects, and thereby account for the full lifetime benefits of road and highway construction. In particular, the current study points to the importance of accounting for road degradation and for the future planned sequence of capital road works, when evaluating new construction of roads and highways.

The strong variation in the (evaluation of the) impact of current capital road works also has implications for analyzing the overall effectiveness of aid programs. Aid effectiveness studies from the past decade have typically relied on macro-econometric panel data regressions, where the average effect of aggregate aid inflows are assumed to be constant across countries and time periods (with some allowance for variation in aggregate policy indices, including trade openness and fiscal prudence) – and across the multitude of country-specific aid-financed projects. However, in the case of road and highway projects, it seems highly unlikely that returns are constant across countries and over time (due to variation in accessible resources and politically-determined minimum road quality levels). Returns are even likely to vary between projects within the same country and time period (due to specific road characteristics including rod surface type, traffic intensity, initial road quality, initial strength of structural foundation, etc.) Accordingly, the current results suggest that there is a need for individual analyzes of aid effectiveness across the wide spectrum of developing countries, and aid-financed projects and programs.

Overall, the results of this study suggest that ex post impact evaluation of road and highway projects does not make much sense (although treatment-effect studies can, potentially, be used for benchmarking purposes). The purpose of evaluating specific projects is to ensure that current funds are being spent wisely. However, road and highway projects have important dynamic effects which may extend over the very long term (15-20 years). In order to achieve timely impact evaluation of road and highway projects, it is therefore necessary to employ ex ante evaluation methods in the form of simulation models. The current application of the CGE-RONET model framework has focused on capturing important dynamic effects and socioeconomic spillover effects associated with specific road projects, but the approach can easily be extended to evaluate road programs for entire road networks.

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