The Impact of Increased Efficiency in the Transport Sectors' Energy Use: A Computable General Equilibrium Analysis for the Botswana Economy[a]

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Abstract

Energy efficiency is viewed as a tool for achieving both sustainable development and environmental sustainability in Botswana and world-wide. This is premised on the standard wisdom that energy-augmenting technical progress reduces aggregate energy consumption. In the energy economics literature, there is disagreement as to whether the beneficial effect of energy efficiency stimulus on energy consumption is partially or wholly counteracted by the negative effect of the response of the economic system to a fall in the relative price of energy services caused by an energy efficiency shock. This paper uses a computable general equilibrium model of energy-economy interactions for Botswana to explore the consequences of energy efficiency enhancement in the transport sectors. These sectors are among those targeted to be energy-efficient by 2016 and are the largest energy-consumers. The evidence shows that efficiency improvement in the transport sectors' energy use stimulates economic activity and results in modest conservation of both total energy and petroleum, but increases non-petroleum use, implying that there are large rebound effects on total energy and petroleum consumption of 95 percent and 91 percent, respectively, and a backfire effect of 101 percent for non-petroleum consumption. The results do not undermine a policy of inreasing energy efficiency, but underscore that government needs to design a package of energy policies if it wishes to achieve energy conservation that will substantially reduce carbon emissions.

Keywords: Energy efficiency, Rebound effect, Backfire, Transport energy demand, CGE Models, Conservation, Botswana

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1 Introduction

Energy efficiency improvement, commonly interpreted as a reduction in energy use for a given level of economic activity, receives attention in Botswana. The reasons for this include rising energy consumption due to both economic and population growth, increased realization that the energy sector is the main environmental polluter and energy supply shortage. In the 2009 Draft Energy Efficiency Strategy (EES) of Botswana, improvement in energy efficiency is viewed as a tool for achieving both sustainable economic development and environmental sustainability. Two questions needing to be addressed are whether energy efficiency stimulus lowers total energy consumption in the economy and, if so, is the energy conservation proportional to an increase in energy efficiency?

The standard wisdom in energy economics argues that energy efficiency enhancements may reduce aggregate energy use, but not by the full extent of energy efficiency shock or they may even increase energy utilisation in the economy. The reason is that the some or all of the energy saving from energy-augmenting technical progress is offset by the response of the economic system to a fall in the relative price of energy services. In the literature, the lost portion of energy saving associated with energy efficiency is called the rebound effect. The size and the character of this effect depend upon the operation of the economy being studied and, hence, cannot be determined *a priori* (Vikstrom, 2004; Hanley *et al*., 2009). The estimate of rebound effect is important in the conduct of energy policy; a high estimate of the rebound effect suggests that energy-saving technologies need to be reinforced with higher energy taxes for technologically achievable carbon reductions and energy conservation to be realised. Furthermore, they may undermine the rationale for energy efficiency policies.

This paper aims to inform policy debate by examining the general equilibrium impact of the efficiency stimulus in the transport sectors' use of energy in Botswana. It also contributes to the energy economics literature on this issue by testing the theoretical conclusion of Sorrell and Dimitropoulos (2008) that the rebound effect may be relatively large in developing countries. Three factors motivating the investigation of the effects of energy efficiency perturbation in the transport sectors are: (i) Energy Statistical Bulletin 2004-05 statistics reveal that this sector consumed 60 percent of commercial energy, making it the largest commercial energy-consumer; (ii) it is among those targeted in the EES 2009 to be energy efficient by 2016; and (iii) the sector is believed to have substantial potential for increases in energy efficiency. The paper uses a computable general equilibrium (CGE) model of the energy-economy for Botswana. A CGE modelling approach is utilised in order to accommodate the argument that a new energy-saving technology causes relative prices throughout the economy to undergo numerous adjustments and, thereby inducing economy-wide responses (Greening *et al*., 2008; Hanley *et al*., 2009). This modelling framework is suited to studying the economy-wide effects of energy efficiency stimulus because it has a multi-sectoral perspective that permits full specifications of all factors influencing energy on both the supply and demand sides. Furthermore, it permits an explicit linkage of energy developments to those variables, such as incomes, consumption and employment, that are the ultimate ends to which energy use is only a means (Jorgenson and Hudson, 1974).

The paper proceeds as follows. The theoretical basis of the rebound effect and empirical evidence is summarised in section 2 in order to enhance an understanding of the results. The social accounting matrix (SAM) for the utilised CGE model is discussed in section 3; and a discussion of the model is presented in section 4. Whilst section 5 reports the simulations; and section 6 draws conclusions.

2 Rebound Effects

This section summarises the rebound effect, with the main purpose of increasing an appreciation of the results. The rebound effect, referred interchangeably as the Khazzoom-Brookes postulate or Jevons' paradox, has generated an extensive literature. The rebound or 'take-back' effect refers to the argument that the expected energy conservation resulting from energy efficiency improvements are partly or entirely offset by increasing demands for energy services caused by technological-induced decreases in the relative price of energy services. In contrast, back-fire effect an extreme version of rebound effect wherein fuel efficiency gains actually increase fuel use (Saunders, 2000). While the theoretical basis of the rebound effect is well accepted, the magnitude of the rebound effect is disputed.

2.1 Theoretical Consideration

The theoretical basis of the rebound effect that originated with Jevons (1865) is developed by Khazzoom (1980), Brookes (1990), Saunders (2000) and Berkhout (2000) in a partial equilibrium setting and by Allan *et al* (2007) and Wei (2007) in a general equilibrium context. This sub-section reviews the rebound effect literature, drawing Greening et al (2000).

The starting point of this counter-intuitive argument is that a new energy-saving technology makes a given unit of physical energy to deliver more energy services than before the energy efficiency stimulus. Energy services are actually the input to the production of output rather than raw energy itself. By increasing the amount of effective energy service delivered, technical progress reduces the effective price of energy services, for a fixed price of physical energy. By the effective price of energy services is meant the price of energy measured in efficiency units (Greening *et al*., 2000; Allan *et al*., 2007). Ordinarily, the fall in the price of energy services induces three countervailing forces. One is denoted as the direct effects in the literature. This happens because a fall in the effective energy price renders energy services relatively cheaper than other inputs and, thereby, encourages profit-maximising firms to substitute energy for non-energy inputs. The adoption of more energy-intensive techniques increases intermediate energy demand. This is the substitution effect. The size of this effect depends upon the elasticity of substitution between energy and other factor. The magnitude of the substitution effect may be zero in the short-run if capital and energy is demanded in accordance with the Leontief technology but larger in the long-run where there is large scope for energy-factor substitutability. Furthermore, the lower price of energy services reduces the overall price of output for a fixed expenditure level and, thereby, increases the profit-maximising level of output. This is the output effect and it stimulates increases in the demands for both energy and non-energy inputs. Thus, the output effect also counteracts energy conservation.

The reduction in the effective energy price has similar effects on final consumption sectors. Firstly, lower energy price induces consumers to substitute the relatively cheaper energy services for non-energy goods. The size of the commodity substitution effect depends upon consumers' satiation threshold levels and trade-offs within their budget constraints. Furthermore, a lower energy bill increases consumers' real incomes and, thereby, enables them to consume more energy and non-energy goods. Thus, the substitution and income effects in final consumption also counterbalance energy conservation associated with the gain in energy efficiency. The direct effects are the impacts on the industry that observed the energy efficiency stimulus.

The second counteracting forces are denoted in the literature as the indirect effects. These are changes in demands in industries in which the technical change did not apply. The sources for the secondary effects are the increased real incomes, reduced production costs and increases in the size of the industry. These factors increase demands for non-energy inputs and for other goods, as well as services that require energy services for their provision in industries that did not witness the energy efficiency stimulus. Here, the costs of products and services that are relatively energy-intensive in production decrease relative to those that are less energy-intensive in production. In other words, the prices of high energy-intensive commodities fall relative to those of less energy-intensive commodities in production. This means that the increases in outputs are particularly more pronounced in energy-intensive industries and in export goods that are energy-intensive in production. Hence, an energy efficiency improvement expectedly causes a composition effect in a multi-sectoral economy. The change in the production structure towards energy-intensive goods is due to the fact that industries producing such goods experience the largest increase in competitiveness. The indirect impact for an industry results, first, from increased demand for non-fuel inputs to the production process due to increased demand for the sector's output and, second, from the effect of the lower cost of one sector's output on production costs of other sectors. Similarly, consumption pattern shifts towards energy-intensive goods and services. The secondary repercussions stimulate energy consumption. In addition, they lead to economic growth, in part, because of the increases in factor demands and, in part, because it stimulates demands of goods and services. Greene *et al* (2000) argue that the indirect effects are likely to be smaller in view of the fact that energy constitutes a small share of an individual consumer's total expenditure and a firm's production cost.

The third countervailing force is denoted as the economy-wide or general equilibrium effects. The sources of these effects are the changes in the relative prices and structural re-configurations due to changes in aggregate consumption patterns. The technology-induced reduction in the effective price of per unit of energy given the resource supplies, consumer preferences and production technologies, cause relative prices of resources and commodities throughout the entire economy to adjust to levels that are mutually consistent with each other. Because prices and quantities of goods and resources in different markets are interrelated, demands and supplies of resources and commodities will respond to relative factor and commodity price changes. Aggregating these micro-level behaviours means that total consumption and investment by both consumers and government should increase. The accompanying structural effect, increased aggregate consumption and investment, as well as employment, associated with the lower energy bill should increase economic growth. In itself, economic growth should raise aggregate energy consumption and, thereby, cause a considerable macroeconomic rebound effect.

Theoretically analysing the effects of energy efficiency improvement, Saunders (1992, 2000), Allan *et al* (2007) and Hanley *et al* (2009) made the following conclusions. First, there is a sound theoretical basis for the rebound effect. Second, backfire cannot be ruled out by theoretical considerations alone. Third, the extent of both the rebound and backfire effects is always an empirical issue. And fourth, the size of the rebound effect crucially depends, among other parameters, upon the elasticity of energy substitution in production and consumption, as well as the degree of openness of the economy.

2.2 Empirical Evidence

There are few studies that empirically investigated the economy-wide effects of energy efficiency. Using a CGE model for the Swedish economy, Vikstrom (2004) found that the energy efficiency shock results in a fairly high rebound effect and in a pronounced structural effect in a multi-commodity environment. For instance, the rebound effect for a 15 percent increase in energy efficiency was around 0.6. Similarly, the CGE model evidence found by Hackley *et al.* (2009) and Allan *et al.* (2007) for the Scottish and United Kingdom economies indicates that the rebound effect is large. For instance, the rebound estimates were 63.2 percent and 54.4 percent for electricity consumption and non-electricity consumption, respectively, for a 5 percent energy efficiency stimulus for the Scottish economy. Their evidence also showed that increases in energy efficiency lead to a substantial compositional effect, with the output, aggregate energy, consumption and trade patterns changing in favour of goods and services that are energy-intensive in production. They also underscored that the responsiveness of goods' demands to relative prices also influences the scale of the rebound and backfire effects in a multiple-commodity and open economy.

3 Database

The CGE model employed was developed and calibrated with an aggregated SAM for the Botswana economy in 1996/97. This is the latest SAM produced by the Central Statistics Office (CSO) in 2002. Unlike the 2004/05 SAM produced for the Global Trade Analysis Project, the utilised SAM is suited for addressing energy-economy issues. A guiding principle in aggregation was to preserve the broad energy-economy transactions. Specifically, the information on energy expenditure by activities and institutions and on the supply of energy from imports and domestic production was retained. Furthermore, the generalised treatment of trade relationships in the CSO SAM was retained and a sufficient disaggregation of the non-energy sectors was allowed. The aggregated SAM retained the two accounts for commercial energy-producing activities, namely, electricity and coal, and the accounts for the three commercial energy commodities, namely, coal, electricity and refinery petroleum. And secondly, the non-energy activities' accounts were treated as follows.

(i) Key activities[1], namely, diamonds, government, textiles, copper/nickel, meat processing and vehicles, were accorded their separate representation. The remaining activities were accorded their separate representation depending upon their energy intensities. Following the recommendation of the UN SNA (1993), the accounts of high energy-intensive[2] activities (road transport and other transports) and medium energy-consumers (construction and other mining)

[1] These are sectors that contribute substantially either to GDP, foreign exchange, employment and/or government revenue. Even though such sectors may be modest energy consumers, developments in such sectors may have important indirect impacts on energy demand and supply. This justifies according such sectors separate representation in the database.

[2] Energy intensity was calculated as the ratio of the cost of energy input to total production cost of an activity. A sector was considered as energy intensive if its oil cost share or electricity cost share or coal cost share exceeded five percent of its total production cost.

have been retained. Low energy-consuming sectors were then aggregated according to their natural groups. These modifications reduced activities from forty-three to twenty-two.

(ii) Non-energy commodities have been grouped based on the classification of activities. Consequently, the number of domestically produced commodities is equal to that of activities. But, there is no one-to-one mapping between activities and commodities. An activity having the same name as the commodity is the main producer of that commodity. For instance, the construction sector produces most of construction commodity, albeit some of it is produced in the sectors for business services, textiles, social services, *etc*. Although each activity produced a characteristic product, the number of commodities exceeded that of activities by one. This is so because petroleum is a non-competitive commodity, i.e., a commodity that is not produced domestically.

(iii) Factors have been reduced to five categories: unskilled citizen labour, skilled manual citizen labour, skilled non-manual citizen labour and non-citizen labour, as well as capital. Distinguishing labour and capital accords with economic theory and empirical evidence, whereas the classification of labour between citizen and non-citizen labour and between the types of citizen labour was made in order to capture functional income distributional changes. Furthermore, differentiating between unskilled citizen labour and skilled citizen labour was informed by the need to accommodate empirical evidence indicating the existence of substantial unemployment of unskilled labour in Botswana. Finally, skilled manual citizen employees are represented separately because the SAM database indicated that this factor accounted for a larger proportion in total employment. Hence, it was important to understand how this important factor responded to a gain in energy efficiency.

(iv) The household sector was reduced to three components, namely, non-citizen, citizen-rural and citizen-urban households. It was believed that this level of aggregation of the household sector was sufficient for analysis of household distributional considerations.

(v) Because this model does not have a financial module, the financial assets accounts have been eliminated. Hence, the model uses the common assumption in CGE modelling that the money is always in equilibrium.

The aggregated SAM comprises of 62 accounts; there are 22 producers, 23 commodities, 5 factors - unskilled citizen labour, skilled manual citizen labour, skilled non-manual citizen labour, non-citizen labour and capital – 3 household accounts, which are rural-citizen, urban-citizen and non-citizen households, seven government accounts, one account each for enterprises, capital-investment and the rest of the world as well as.four other accounts. It is believed that this aggregated SAM sufficiently captures the energy-economy interactions in Botswana. The CGE model for this paper has been built around this aggregated SAM. Hence, the model captured the actual transactions of the Botswana economy recorded in the 1996/97 SAM. The next section presents the key features of the model utilised.

4 The CGE Model

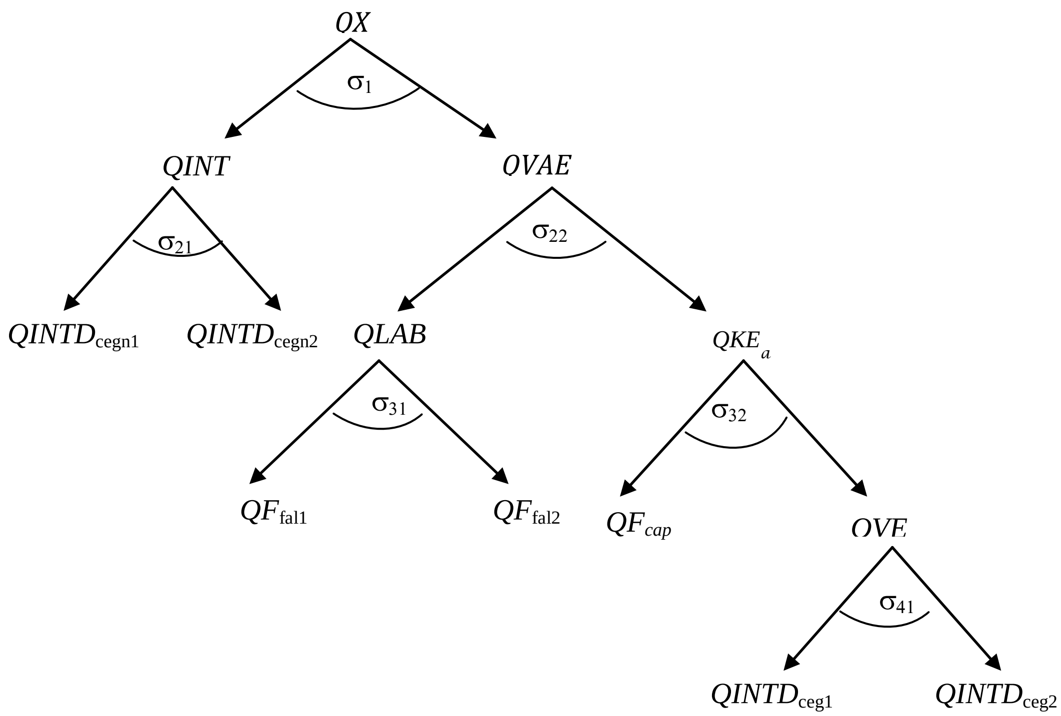
The application of CGE models to energy efficiency is gaining popularity. CGE models are a class of multi-sectoral and price endogenous models that are based on actual transactions and that simulate the workings of market economies. Their distinguishing feature is that optimisers respond to relative prices, i.e., changes in relative prices signal to agents the need for altering their production, trade and consumption patterns. They are advantageous in studying the economy-wide effects of an energy efficiency stimulus because their multi-sectoral perspective permits full specifications of all factors influencing energy on both the supply and demand sides. Furthermore, they permit an explicit linkage of energy developments to those variables such as incomes, consumption and employment that are the ultimate ends to which energy use is only a means (Jorgenson and Hudson, 1974). CGE models allow for endogenous interactions of all sectors in the economy. Hence, a CGE modeling framework that has been developed and parameterized on the Botswana database, hereafter referred to as the BOT-CGE, is used.

The BOT-CGE is developed by incorporating an energy substitution structure and other features onto the standard CGE model by Lofgren *et al* (2001). The standard CGE model is advantageous in that its structure accommodates a wide range of features of Southern Africa economies, such an unemployment and activity-inspired restrictions, contains a wide range of policy instruments and its code structure is available without cost. The incorporated features rendered the standard CGE model appropriate for the investigations in this paper. Substantial modifications are made to the structure of production. Specifically, the energy substitution is incorporated using the energy/capital separability assumption. It is assumed that substitution possibilities exist between energy and capital, between energy and labour, between capital and labour, but not between energy and other intermediate inputs. This nesting production structure is preferred because of its appealing theoretical basis provided by Balestra and Nerlove (1966) and for its flexibility in the handling of the issue of capital-energy substitutability or complementarity. Given the level of aggregation of capital in the SAM, it is plausible to assume that capital consists of a mixture of different types of capital commodities (Johansen, 1960; Kuper, 1995) and, hence, *ex post* substitution possibilities between energy and capital in response to changes in the relative prices of energy are possible even when the volume of capital stock remains fixed. This can occur as a result of transformations in capital goods such as retrofitting, modifications in automobile designs, *etc*., that leaves the stock of capital fixed. In such a case, the capital-energy quantity ratio will respond to changes in relative prices. In contrast, changes in technologies through transformations in capital goods may not be possible in the short-run. For this case, the optimal energy-capital ratio is invariant to changes in relative prices. Currently, there is disagreement as to where in the production structure energy should be introduced.

4.1 Production

Activities are assumed to maximise profits subject to a four-stage production technology, the structure of which is shown in figure 1. At the top-level, gross output is a CES function of non-energy intermediate ($QINT_a$) and value added-energy ($QVAE_a$) composites. At the second-level, value added-energy is a CES aggregator function of aggregate labour ($QLAB_a$) and a capital-energy (QKE_a) composite, whilst the aggregate non-energy intermediate is a Leontief function of multiple non-energy intermediates. At the third-level, labour aggregate is a CES function of the various types of labour and the capital-energy aggregate (QKE) is a CES function of capital (QF_{cap}) and aggregate energy (QVE). Finally, aggregate energy, at the fourth-level, is a CES function of coal, electricity and petroleum. This underscores that the demands for labour, capital and energy inputs are first-order optimality conditions. They are derived from constrained optimization problems as require by economic theory. Non-energy intermediate inputs are demanded in fixed proportions to aggregate non-energy intermediate composite.

Figure 1: BOT-CGE Model Production Structure in Quantity Terms



The use of a nested production structure approach is unavoidable when there are many inputs. This allows a modeller to use less complex functional forms that are tractable, parsimonious in the use of data and are well-understood, and, at the same time, permit model flexibility to be increased. Furthermore, the approach keeps the optimisation problem computationally manageable. Besides the fact that the estimation of their parameters is unmanageable, when there are many inputs, as is typically the case in CGE models, and the data needed for estimating their parameters - particularly on the intermediates - is normally unavailable, Perroni and Rutherford (1995, 1998) have shown that flexible functional forms, such as the generalised Leontief function, are prone to loss of global regularity. This causes numerical solution methods to fail even when functions are well-behaved at the equilibrium points. Consequently, they are deemed unsuitable in CGE modeling, where the preservation of the initial calibration information over the domain of the modelling exercises assumes importance.

The modelling of production of multiple commodities is accommodated using fixed yield coefficients. Specifically, the proportionate combinations of commodity outputs in the SAM produced by each activity are assumed fixed. This implies that for any given vector of commodities demanded there is a unique vector of activity outputs that must be produced.

4.2 Trade

Trade relationships are modelled using the small-country assumption in conjunction with the Armington (1969) presumption of product differentiation. Accordingly, domestically produced commodities are imperfect substitutes of both exports and imports. Imperfect substitution between the imported (*QM*) and domestically produced commodities (*QD*) is captured by CES functions. Similarly, imperfect transformability between domestic and export commodities is captured by a constant elasticity of transformation function. Here, the argument is that domestic and exported commodities with the same sectoral classification are commodities of different qualities or sub-sector classification (Robinson, 1988). Some of the virtues of this standard approach in CGE models are (de Melo, 1988): (i) it grants the domestic price system some degree of autonomy from world prices; and (ii) it accommodates the trade statistics indicating the occurrence of substantial cross-hauling, i.e., importing and exporting same commodity, which is the case in Botswana.

4.3 Final Consumption

Households are assumed to maximise utility subject to Stone-Geary utility functions, which has a virtue incorporating allowances for subsistence levels of consumption. Therefore, it is preferable since Botswana has a substantial number of poor households. Final demands by government and investment are modelled under the assumption that the relative quantities of each commodity demanded by these institutions are fixed at their base levels. This reflects disagreement on clear theories defining the appropriate behavioural responses of investment and government to changes in relative prices.

4.4 Model Closures

The default closures of the standard model are also changed in line with the objective of this paper. The default closures of the model and subsequent simulations are as follows.

(i) The prices and quantities of all commodities are endogenously determined. Besides being easy to implement, this standard closure for the commodity markets renders the demand elasticities to be reflected in the general equilibrium character of the model (Burniaux and Truong, 2002: p.47).

(ii) The consumer price index is the numeraire. Among other things, this closure implies that the nominal domestic absorption is the appropriate measure of welfare (Arndt *et al.*: 1999, p.8).

(iii) The world prices of all tradable goods are fixed as per the small-country assumption and the exchange rate has been fixed. This is based upon the observation that Botswana follows a crawling-peg exchange rate regime.

(iv) And finally, the short-run closure for the factor market is adopted. Firstly, capital is activity-specific and fixed in supply, reflecting the observation that capital is scarce in developing economies (Maio *et al*, 1999). Furthermore, this study assumes that the time period that is insufficient for the newly purchased capital goods to be installed and used. Secondly, supply of unskilled labour is assumed to be perfectly elastic which accomodates the labour statistics indicating prevalence of substantial unemployment. This means that wage for unskilled labour is fixed. However, the supplies of all types of skilled labour are fixed at their base levels and wages for types of unskilled labour vary. But, each category skilled labour is inter-sectorally mobile.

The fixity of the economy-wide wage of unskilled labour and of the quantity of the activity-specific capital means that this model is recast from its long-run mode to the short-run and comparative static mode. Hence, the experiments are conducted in an economic scenario characterised by rigidities. This is informed by the argument that policy analysis must be conducted within the third-best environment in African economies (Maio, 1999).

Estimation of Behavioral Parameters

In addition to the SAM database, the values of substitution elasticities of the CES production and trade functions, as well as of the linear expenditure systems, are needed in the CGE model calibration. Due to the dearth of econometric studies on energy-factor substitutions and an energy-focused CGE model with a CES nested production function for developing countries, there is insufficient empirical evidence that can been used to assign values to substitution elasticity parameters. Consequently, all the substitution elasticities are, as is common in CGE modelling, extraneously determined. It is, therefore, useful to provide an account of how the substitution elasticity estimates were obtained. Here, the focus is on production elasticities.

In all the activities, the elasticity of substitution between value-added/energy and non-energy intermediate input (σ_1) at the first-level nest in figure 1 is assumed to be 0.2, implying a presumption that the quantity ratio of non-energy intermediate to value added-energy composite is almost unresponsive to changes in its relative price. The elasticities of substitution between capital-energy and labour (σ_{22}) in second-level nest, between labour inputs (σ_{31}) and between energy and capital (σ_{32}) at third-level, as well as between energy inputs (σ_4) at the fourth -level for the services' sectors, are assumed to be 0.9, 0.9, 0.6 and 0.9, and for the transport sectors to be 0.5, 0.5, 0.2 and 0.4, respectively. The corresponding elasticities for the non-services' sectors are set at 0.7, 0.7, 0.4 and 0.6, respectively. Note that the elasticities in two consecutive nests are assigned different values. This increases model flexibility.

It is apparent that the adopted elasticity values are low, implying that a one percent change in the effective price of energy will elicit a less than proportionate change in, for instance, the energy-capital quantity ratio in each sector. The adoption of low elasticities follows from both the theoretical argument and empirical evidence indicating that substitution elasticities are generally low in the short-run. This is because the costs associated with shifting to a different technology, such as retiring obsolete capital, hiring or firing workers, *etc*., are generally perceived to be high. These high transfer costs constrain producers from revising their past decisions in the short-run and, thereby, limit the scope of factor substitution in the short term. The presumption that the services sectors have higher substitution elasticities than the primary industries is founded on the Hudson and Jorgenson (1974) economic reasoning. Hudson and Jorgenson (1974) explained differential relative elasticities by bifurcating energy use into discretionary - defined as energy needed for comfort functions such as heating and cooling, as well as personal services such as automobile travel - and process, defined as fuel for driving machinery, heating materials, turning generators, *etc*. According to them, the ratio of discretionary to process energy use is perceived to be low for services, lower for industries and lowest for the electricity-producing activity. Consequently, the elasticities for services should be relatively higher than those for industries.

5 Simulations

Due to its large size and non-linearity nature, the BOT-CGE is implemented as a mixed complementarity problem in the General Algebraic Modelling System (GAMS) software and solved by *PATH*. Given the substitution elasticity values, it is parameterised to the 1996/97 SAM for Botswana. It is run until the general equilibrium solution reproducing the SAM transactions it is calibrated to is computed. This baseline run of the BOT-CGE is the reference point against which the changes induced by energy efficiency disturbance are measured, i.e., it is the counter-factual in this paper. This means that, prior to the energy efficiency change, the Botswana economy is assumed to be in long-run equilibrium in 1996/97. Re-running the BOT-CGE in the absence of any perturbation reproduces the initial equilibrium solution. Then, the efficiency with which the transport sectors combine the energy composite with capital is changed consecutively by various percentages. Note that petroleum and electricity are the only energy inputs used in the transport sectors, with petroleum accounting for 95 percent of transport sectors' total energy use. Therefore, the simulations actually capture the effects of the change in the efficiency with which the transport sectors combine petroleum and electricity with capital in their production functions. Thus, the technical efficiency shock is imposed as an energy-augmenting change to the energy composite only in the transport sectors. The consequential changes in selected energy and economic indicators are reported as the percentage changes from the baseline values given in the aggregate SAM. The reported results refer to percentage changes in the endogenous variables relative to this unchanging equilibrium. Therefore, all the effects are directly attributable to the energy efficiency stimulus.

Instead of one, a group of simulations are run. The reason for this is to ascertain whether the changes to the economy due to energy efficiency are consistent in the sense that there are no instances of discontinuity or jumps in the results.

5.1 Results

An examination of the results of several simulations ascertained that the pattern of changes to the economy is consistent in that there are no discontinuities in the results. Hence, only the ramifications of a 10 percent increase in energy efficiency are reported. Note that since the BOT-CGE is cast in a comparative static mode it neither accounts for second-period effects nor is it specific about the time horizon of the adjustment. Hence, the reported results are not time path dependent.

Three main observations emerge from the results of a 10 percent energy efficiency increase in the transport sectors that are reported in table 1. First, total energy consumption decreases by 0.44 percent. This translates to a very large macroeconomic rebound effect of 96 percent. This means that 96 percent of energy conservation associated with a 10 percent efficiency stimulus is taken-back by the general equilibrium effects of efficiency gain. The largest relative contribution to the macroeconomic rebound effect comes from final consumer, followed by non-transport industries, and the lowest emanates from the transport sectors. The demand for aggregate energy for final consumption rises marginally by 0.1 percent and for total intermediate consumption falls by 0.66 percent. The transport sectors experience a relatively large cutback in intermediate energy consumption of around 6 percent, whilst the relative decline in other industries is less than 1 percent, implying a rebound effect of around 40 percent in the transport sectors. This indicates that the positive effect of increased energy efficiency outweighed the negative impact of the substitution, output and income effects on energy use in the transport sectors. Thus, the evidence suggests that, for maximum effect, energy conservation policies should give as much weight to reducing final demand and intermediate demand of the non-transport activities. Indeed, the evidence supports Sorrell and Dimitropoulos' (2008) theoretical conclusion that the rebound effect may be larger in developing countries. Note that the rebound effect is calculated, following Berkhout *et al* (2000), Vikstrom (2004) and Barker *et al* (2007), as the difference between energy saving predicted by the engineering calculation and the energy saving derived from the model simulation expressed as a percentage of the gain in energy efficiency.

The second and striking feature of the results is the presence of both rebound and backfire effects. Consumption of petroleum falls by 0.86 percent, whilst that of both coal and electricity increases from the baseline level by 0.1 percent. This indicates a large rebound effect on petroleum consumption of 91 percent and a small non-petroleum energy backfire effect of 101 percent. The intriguing presence of rebound and backfire effects is attributable to the energy consumption pattern of the transport sectors. It is petroleum intensive, with petroleum accounting for 95 percent and electricity accounting for only 5 percent of the transport sectors' total energy cost. Moreover, the transport sectors are the largest petroleum consumers in the economy. Consequently, the increase in energy efficiency causes the largest change in the effective price of petroleum and the lowest for electricity and, thereby, leads to the greatest impact on petroleum demand. Thus, the positive effect of the change in energy efficiency outweighed the combined negative impact of the substitution, production and income effects on petroleum consumption, whilst the effect of the latter dominated in total electricity use.

And third, the improvement in technical efficiency stimulates economic activity. Real GDP increase by 0.3 percent, respectively. Employment of unskilled labour rises by 0.87 percent, whilst the prices of factors whose demands are fixed by model closures increase. The increases in wages of skilled labour types range from a low of 0.93 percent for non-citizen labour to a high of 1.04 percent for skilled manual labour. The increase in the price of capital of 1.25 percent is the highest. The changes in demands for unskilled labour and factor prices are responsible for the increase in value added.

Table 1: Effects of Efficiency Gain in the Transport Sectors' Energy Use

	Percent change from base year
Real GDP at market prices	0.35
Domestic absorption	0.43
Real household consumption	0.50
Total investment	0.21
Government consumption	0.60
Government savings	0.03
Total exports	0.17
Total imports	0.25
Foreign savings	0.0
Domestic good	0.51
Unskilled labour employment	0.87
Non-energy intermediate consumption	0.50
Energy intermediate consumption	-0.66
Total energy consumption	-0.04
Petroleum Consumption	-0.86
Coal Consumption	0.10
Electricity consumption	0.07

Source: Model Simulation

There is also evidence of household welfare improvement. Real household consumption increases by 0.5 percent. Nevertheless, the welfare effects vary across households. The equivalent variation (EV) estimates, calculated in money metric welfare functions and on the basis of household utility changes in relation to this simulation, are -0.03 percent for urban households, 0.06 percent for non-citizen households and 0.21 percent for rural households. The differences in welfare effects are attributed to changes in household incomes; the rises in incomes are 0.81 percent for urban households, 0.79 percent for non-citizen households and 0.77 percent for rural households. The other main factor in explaining the welfare effects is the difference in their consumption patterns. There is evidence that consumption increased most for transport services and for goods/services having high incidence of transport services intensity in production as such goods/services become relatively cheap. Such commodities are typically consumed by urban households.

The afore-going discussion undoubtedly underscores that the rebound effect is a nuisance from the perspective of the utilisation of energy efficiency enhancements as tools for reducing environmental pollution. Nonetheless, it is a positive thing from the perspective of economic activity as it transformed technical efficiency into economic growth, employment creation and household welfare gain.

Whilst an energy-augmenting technological change has beneficial macroeconomic effects, it may have undesirable sectoral effects. Table 2 shows the impact on sectoral output volumes and prices. Not only are the adjustments of the output prices clear-cut, but they are also generally in line with the importance of the transport service in the sectors' production costs. The decreases in output prices are largest, over 8 percent, for the transportation sectors and are smallest for the other mining (0.98 percent) and government (0.1 percent) sectors. Conversely, output prices increase for the remaining sectors. The increases in output prices of the transport sectors are unsurprising; first, the increase in energy efficiency applies only to these sectors, implying that they are the only ones that witness decreases in the effective prices of energy services; and second, their energy intensities are largest in the economy, amounting to 21 percent and 10 percent in the road and other transport sectors, respectively. Consequently, the decreases in energy composite prices outweighed the effect of the increases in factor prices in the transport sectors. The changes in output prices of non-transport industries generally reflect sectoral differences in the intensity of transportation services in their production costs. Output prices decrease in industries that have a high intensity of transportation services, notably other mining and government, and the increases in output prices are smallest in industries that are intensive users of transportation services. The SAM database indicates that the share of transport services in the production costs of the other mining and government sectors are 13.5 percent and 7 percent, respectively, compared to those of other industries that range from a low of 0.10 percent in diamonds to a high of 2.53 percent in meat and meat products. Thus, the figures show that the transport sectors observe the largest increases in competitiveness through reductions in their output prices, followed by other mining and government sectors in that order.

The impact on the output volumes is also straight-forward and is generally consistent with adjustment of output prices. Invariably, all the industries benefit from the efficiency increase, albeit by differing degrees. The transport sectors are, unsurprisingly, the largest gainers, with their output increasing by over 2 percent, followed by intensive users of transport services, notably other mining (0.98 percent) and government (0.57 percent), as well as some non-export-oriented sectors, dairy products (0.53 percent) and, notably, hotels and restaurants (0.53 percent). With exception of textiles (0.57 percent) and metal goods (0.44 percent), export-oriented sectors are in generally the smallest gainers. The output results suggest that the production structure shifts away from export-oriented industries and towards transport industries and intensive-users of transport services.

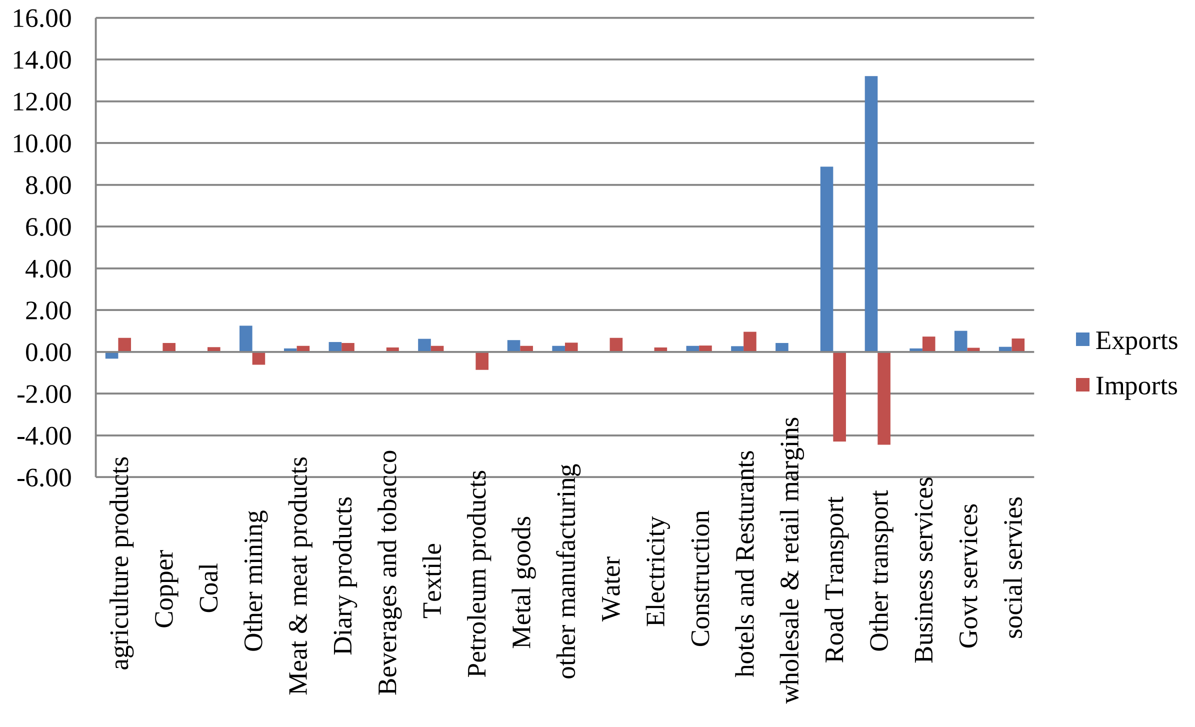
Table 2: Effects of Energy Efficiency on Sectoral Output and Prices (Percent Change)

Activity	Output	Prices
Agriculture product	0.16	0.60
Copper	0.05	0.32
Coal	0.08	0.42
Other mining	0.98	-0.56
Meat & meat product	0.23	0.29
Diary products	0.53	0.27
Beverages and tobacco	0.13	0.34
Textile	0.57	0.17
Metal goods	0.44	0.11
Other manufacturing	0.33	0.32
Water	0.36	0.62
Electricity	0.04	0.49
Construction	0.29	0.25
Trade	0.35	0.18
Hotels & Restaurants	0.53	0.46
Road Transport	2.36	-9.48
Other transport	5.25	-8.29
Business services	0.10	0.62
Govt services	0.57	-0.10
Social services	0.24	0.58

Source: Model Simulation

It is also fruitful to consider the implications of the gain in energy efficiency on foreign trade. The results on exports and import volumes reported in figure 2 are straight-forward. First, both aggregate exports and imports measured in constant prices increase, with the increase proportionally large for imports. Second, there are changes in the compositions of exports and imports. Specifically, the imports composition changes away from transport services, petroleum and commodities/services that have high incidences of transport intensities in their production, while that of exports changes towards transport services and commodities that are generally large users of transport services in production.

Figure 2: Effects on a 10 per cent Energy Efficiency Gain on Exports and Imports volumes



5.2 Sensitivity Analysis

Several sensitivity tests are conducted. The purpose of sensitivity analysis, which is of crucial importance in a calibrated CGE model, is to gauge the robustness of the results to alternate behavioural parameter values. In the sensitivity tests, the energy efficiency disturbances are simulated under alternate substitution elasticity values. This sub-section reports only the results of varying the elasticity of substitution between energy and capital.

For this set of sensitivity tests, the values of the energy-capital substitution elasticity parameters (σ_{32}) are changed. This is the point on the third level in the production structure of the BOT-CGE in figure 1. Specifically, the energy-capital substitution elasticity values for the services, transport and non-services sectors are set at low values of 0.4, 0.1 and 0.2, respectively. The corresponding high values of energy-capital substitution elasticity are 0.9, 0.4 and 0.6, respectively. The expectation is that it will be difficult for agents to substitute energy for non-energy inputs. Table 3 reports the results of these simulations. The figures show that there is energy conservation in all cases. However, energy conservation varies with the value of energy-capital substitution elasticity. Aggregate energy consumption decreases by 0.28 percent in the low elasticity case and by 0.77 percent in the high elasticity case, compared to just 0.49 percent in the base elasticity case. The energy consumption rebound effect is 92 percent in the high energy-capital substitution elasticity case and 97 percent in the low elasticity case. Similarly, increases in both coal and electricity consumption are largest, at 0.23 percent and 0.12 percent, respectively, in the high elasticity case and lowest, at 0.05 percent and 0.05 percent, in the low elasticity case. The corresponding backfire effects for coal are 101.2 percent and 100.5 percent for the high and low elasticity cases, respectively, and for electricity are 101.2 percent and 100.5 percent, whilst the petroleum rebound effects are 86.2 percent and 95 percent for the same two cases, respectively. The figures suggest that the occurrence of both the petroleum consumption rebound effect and coal and electricity consumption backfire effects cannot be attributed to the value of elasticity of substitution between energy and capital.

Table 3: Effects of Alternate Elasticity Substitution between Energy and Capital on the Macroeconomy (Percent Change)

	Low	Base Case	High
Real GDP	0.36	0.35	0.35
Household consumption	0.51	0.50	0.49
Investment spending	0.19	0.21	0.23
Government consumption	0.62	0.60	0.57
Exports	0.19	0.17	0.14
Imports	0.28	0.25	0.22
Total Energy Consumption	-0.03	-0.04	-0.07
Electricity Consumption	0.05	0.07	0.12
Petroleum Consumption	-0.50	-0.86	-1.38
Coal Consumption	0.05	0.10	0.23
Unskilled labour employment	0.89	0.87	0.81
Energy intermediate input	-0.39	-0.66	-1.05
Non-energy intermediate input	0.53	0.50	0.47

Source: Model Simulation

It is also evident that there is economic growth, welfare gain and employment creation in all the cases of energy-capital substitution elasticity values. However, the magnitude of economic expansion, welfare improvement and employment creation are influenced by the energy-capital substitution elasticity. Similar observations were obtained for the other substitution elasticity values. Thus, the sensitivity tests indicated that the qualitative predictions are robust to alternate values of the substitution elasticity values, while the scales of the impact are sensitive to variations in the behavioural parameter values.

6 Conclusions

The paper investigated the effects of an efficiency stimulus in the transport sectors' energy use. The transportation sector is the largest commercial energy consumer and is targeted to be energy efficient by 2016. Therefore, it was of interest to explore the likely consequences of an improvement in efficiency in this sector on total energy consumption and on key economic indicators. An energy-economy CGE model for Botswana was used to obtain the results. This modeling framework was used, in part, because of its increasing application in changes in energy efficiency and, in part, because of its virtues of permitting systematic analysis of factors that influence energy on both the demand and supply sides and permitting explicit linkage of energy developments to those variables, such as employment, incomes and consumption, that are the ultimate ends to which energy use is only a means. This approach is, therefore, a useful tool for capturing the general equilibrium consequences of energy efficiency shocks.

The main conclusion of this paper is that an increase in efficiency in the transport sectors' energy use in a single and open economy lowers total energy consumption. However, the resultant energy conservation is proportionally less than the energy efficiency improvement or the amount suggested by an engineering calculation. Aggregate energy saving is about 0.5 percent in the face of a 10 percent increase in energy efficiency, indicating that there is a large energy consumption rebound effect of 0.95. Another main conclusion is that it is possible for both the rebound and backfire effects to occur in the short-run. Consumption of petroleum decreases, but increases for non-petroleum energy. The other main prediction is that it will generate economic growth, employment creation, household welfare improvement and structural changes. This means that, whilst the rebound effect is a nuisance from the perspective of utilisation of energy efficiency enhancements as an instrument for reducing carbon emissions, it is positive from the perspective of economic activity. The qualitative predictions are robust to changes in substitution elasticity values, whilst the magnitudes of the effects are sensitive to variations of substitution elasticity values.

Far from undermining the efficacy of energy efficiency enhancement policies, this paper makes an important point that exclusive reliance on increases in energy efficiency alone cannot secure substantial energy conservation and sizeable reductions in pollutants. Furthermore, it offers a clear guidance on the appropriate conduct of energy policy. Energy policy makers wishing to mitigate the unintended effects of energy efficiency enhancement need to design a package of energy policy measures in such a way that it achieves substantial energy conservation and reduction of pollutants without inhibiting the preconditions for economic growth induced by energy efficiency stimulus. Like Hanley *et al.* (2009), it endorses the advice of Birol and Keppler's (2000) that an energy policy combining increases in energy efficiency with energy taxes offers the potential of a genuine double dividend of simultaneous economic and environmental gain.

These predictions must be used taking into account the following limitations inherent in the utilised CGE model. Firstly, the employed CGE model is based on the real economy. Hence, there is a maintained presumption that there are no financial implications of the energy efficiency shock and changes in the monetary sector have no consequential effects on the real economy. Future research could allow the feedback effects to the real economic sectors via the monetary variables to be captured by incorporating a financial module in the model. Secondly, the utilised CGE model is a single-period and static equilibrium model. Hence, it is incapable of predicting the dynamic implications of energy efficiency improvement and the predictions are not time path dependent. Thirdly, the values of the behavioural parameters of the model were guess-estimated using economic reasoning and literature estimates. It would be interesting to empirically estimate, data permitting, the model's behavioural parameter values using either the econometric techniques or maximum entropy method and examine whether the predictions from such a model differ from the results obtained with this model. And fourthly, the simulation results have been generated under the same set of closure rules. Hence, the results may be specific to the adopted closures. In view of some existing empirical evidence indicating that the choice of model closures affects the results, it would be interesting to run these simulations under alternate macroeconomic and factor closure rules.

The aforementioned limitations and/or issues are always encountered in the CGE modelling framework. As many have emphasised, the important point is that the model should be evaluated in terms of its suitability to the questions it is designed to address and the extent to which it is capable of emulating the operation of the economy being studied. In the context of the Botswana economy, the CGE model that was employed was appropriate for addressing this issue and also yielded plausible predictions.

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