A CGE MODEL WITH ENDOGENOUS SOIL FERTILITY:
MAIZE TRADE LIBERALIZATION vs. FERTILIZER SUBSIDIES IN TANZANIA:

By

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ENDOGENOUS SOIL FERTILITY

Abstract

This paper presents an analysis on economy-environmental interlinkages by using a computable general equilibrium (CGE) model in order to evaluate two policy measures meant to stimulate growth and crop production in Tanzania. The model is multisectoral with a particular focus on crop producing sectors and soil mining processes. The analysis shows that both policy reforms have expansive effects and that significant sectoral complementarities do exist between agriculture and non-agriculture in Tanzania. Fertilizer subsidies promote cash crop production and a more land intensive production pattern, while maize trade liberalization, on the other hand, stimulates food crops and land extensive production processes. Only minor effects are identified for both reforms as concerning their impact on distribution and soil erosion.

JEL classification: C68, Q18, Q24

Keywords: CGE; Soil fertility; Trade reform, Input subsidy.

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1. Introduction

Various avenues for achieving economic growth in developing countries are discussed in the literature. Most of the strategies are linked to trade or to specific sectors in the economy. One controversy is whether to encourage export promotion or import substitution. Another is whether to promote an agriculture-oriented strategy rather than industry-driven growth. Many studies find agriculture in developing countries to be a neglected sector. One obvious reason is the believed gap between potential and actual agricultural performance in developing countries. Another reason is growth linkages that agriculture may have with other sectors in the economy (see e.g. Singer 1982, Rao and Caballero, 1990). Hwa (1983) finds that countries with a high agricultural growth are more likely to have a high industrial growth as well.

Tanzania has undergone major changes and reforms the last 10 years most of them a consequence of structural adjustment programs. The reforms have reduced governmental intervention and strengthened the role of the private sector. In spite of liberalization of virtually every aspect of the economy, additional reforms are being considered. A recent discussion is about further reforms in the agricultural sector. Grain exports are still restricted in Tanzania and can only be conducted through licenses obtained from regional authorities. Critics of this policy are of the opinion that Tanzania rather should take advantage of its favored position for supplying maize to neighboring countries. A different reform, also discussed in the literature, is the application of fertilizer subsidies to stimulate agricultural production.

In our opinion, the two suggested policy reforms, can best be analyzed within a CGE framework for which economy-environmental (soil) interlinkages are included. The incorporation of environmental considerations in CGE-models is a recent development in the literature. Deforestation processes are studied in works on Nicaragua and Costa Rica (Glomsrød et al., 1997; Person and Munasinge, 1995). Unemo (1993) analyses overgrazing of rangelands in Botswana due to property right externalities. Our analysis on Tanzania represents a continuation and extension of two former CGE modeling approaches on soil erosion (see Alfsen et al., (1996) on Nicaragua and Alfsen et al.,

(1997) on Ghana). Alfsen et al., (1996) applies subjective soil expert assessments to determine the relationship between soil and productivity losses (exogenous relationships), and these estimates are then fed into the CGE model. Alfsen et al., (1997) improves on this approach by modeling soil degradation as an endogenous processes being dependent on agricultural production. However, the model is still not fully satisfactory, since chemical fertilizers and soil fertility remain two independent factors in agricultural production. Soil productivity (soil nitrogen) appears as a Hicks-neutral technical change in that soil fertility enters the agricultural production functions in a multiplicative manner. Chemical fertilizer, on the other hand, is assumed to be a standard production factor. Our study on Tanzania extends the above approach in two respects. First, chemical fertilizers and natural soil nitrogen are modeled as one variable, only, since both supply the soil with higher fertility. In regions where soil nitrogen is a limiting soil productivity factor (such as in Tanzania), natural soil nitrogen and chemical fertilizers become perfect substitutes in crop production (nitrogen). Second, nitrogen does not enter the agricultural production function as a multiplicative constant but as a standard factor of production.

The outlay of this study is as follows. In the next chapter the two suggested Tanzanian policy reforms are discussed. In section 3 some background on the Tanzanian economy is presented. In section 4 the CGE model is presented in more detail, while the policy simulations are described in section 5. Section 6 concludes.

2. Fertilizer subsidies and trade liberalization

In spite of the reforms, average agricultural yield still remains low in Tanzania, and is about a third of world average, which indicates a potential for domestic production increases. During the 80s Tanzania was a net importer of maize, but have been self- sufficient in maize production from the late 80s. Exports of maize can only be conducted if export licenses from regional authorities are obtained. At the same time illegal cross-border trade of maize is observed. The reluctance to promote maize export, as a means to stimulate agricultural production, arises because of concerns of risking food security and food self-sufficiency rates. The consequence of export barriers is suppressed prices and thus cheaper food available for domestic consumers (landless and the urban sector). At the same time barriers to export act as a disincentive for agricultural producers. Putterman (1995) is of the opinion that Tanzania's aggregate grain output could expand if international markets were to be exploited. Exports of grains would expect to increase grain prices and make agricultural production become more profitable. Tanzania should go ahead to follow strategies that take advantage of its favored position for supplying food to landlocked countries in Eastern and Southern Africa. «There is an increasing recognition of the need to relax official constraints on grain-exports to neighboring countries» (World Bank, 1996, p. 15). At the same time food security concerns can be met due to Tanzania's easy access to international supply sources in seasons with crop failures.

There are, however, views that challenge the above strategy. Coulter and Lele (1993) find that barring grain exports remains appropriate for the medium term and instead advocate a subsidy on fertilizers to induce progress and agricultural modernization in Tanzania. Similar suggestions are found elsewhere in the literature. Lele et al., (1989) considers increased use of chemical fertilizers as a crucial ingredient in raising agricultural output. Rao and Caballero (1990), when discussing agricultural input subsidies, stress the importance of focusing on fertilizers rather than on labor saving inputs in order to achieve gains in terms of employment.

The current application of fertilizers is considered to be much too low in Tanzania. The potential yield of many crops can be increased two to four times by using higher levels combined with improved cultivation techniques (Putterman, 1995; Lal, 1993). The average fertilizer rate per hectare in Africa is about 20 kg per hectare, compared to 41 kg in Latin America, 85 kg in Asia and 225 kg in Western Europe (FAO, 1996). The recent awareness of reductions in the natural productivity of soils in low-input external agriculture has given renewed support to fertilizer subsidization. Former reforms that removed such subsidies are now being accused of having neglected positive externalities. A higher fertilization rate can arrest soil erosion processes by providing land with a better vegetation cover against erratic rain and a better root structure (Aune et al., 1995; Grepperud, 1997). An additional rationale for fertilizer subsidies is the persistence of other market imperfections such as cash and credit constraints. Holden and Shanmugaratam (1994) argue for agricultural production subsidies in combination with more use of soil conservation measures to promote agricultural intensification while conserving and enhancing soil capital. The role of fertilizer subsidies has been addressed in the debate on high-input versus low-input strategies in LDCs (see e.g. Reardon, 1989; Kesseba, 1989; Hansen, 1990). For some tropical soils, however, there are few low-input substitutes - mulching, compost and manure - available (Lal, 1993; Repetto, 1987).

The two policy reforms both focus on the role of prices in order to achieve an agricultural push.[1] Input subsidies are clearly a direct price intervention while the promotion of free trade is of a more indirect nature. Both reforms can also be viewed as short-term policy measures but differ with respect to the role of governments. Putterman's (1995) advice is neoclassical since trade liberalization implies an inactive government (deregulation). Coulter and Lele (1993), on the other hand, emphasize the role of government when suggesting input price intervention.[2] However, former literature on the two reforms has ignored two important considerations. The first concerns the effects reforms may have on the environment. Chemical fertilizer is a key input in agriculture with a potential to offset soil mining processes as well as soil erosion while maize is a particularly erosive crop. In this perspective, any analysis on agricultural reforms should direct attention to environmental implications. The second consideration is about budgetary implications. Input subsidies have a direct negative impact on budgets, while a lifting of export regulations has no such direct effect. A trade liberalization that is combined with an export-tax may in fact increase public revenues. This observation is important and implies that it is not straightforward to conduct a policy comparison of the two reforms. Subsidies need to be financed while a trade reform does not. Consequently, the purpose of this analysis is not to answer the question of which of the reforms is preferable. Rather an attempt is made to identify

[1] To what degree agricultural output responds to prices is discussed in Binswanger (1990) and Rao (1989).

[2] The debate on input subsidies vs. export promotion in Tanzania has similarities with literature on whether to apply output price subsidies or input subsidies to promote rice production in Asia (Barker and Hayami, 1976).

additional effects (including environmental ones) that may be of importance when discussing the adequacy of each reform.

3. Changes and challenges in the economy of Tanzania.

Agriculture accounts for more than half of the Gross Domestic Product (GDP) in Tanzania and is the crucial source of employment - about 80 percent of the population works in this sector. There are about 3.5 million farmers in Tanzania cultivating more than 4 million hectares of land. In addition more than 1 million hectares are occupied by about 700 larger farms mainly owned and operated by parastatals. Agricultural exports are lower now than in the 1970s, and agricultural productivity is lower than the LDC average. The unemployment rate in Tanzania in 1996 was estimated to be about 11 percent (World Bank, 1996).

In the first years following the 1961 independence, agricultural output expanded rapidly in Tanzania. Input delivery and marketing systems were well functioning and world market prices were favorable (World Bank, 1991). The economic policy in this period was a continuation of pre-colonial policies. The end of the 60s the country embarked on a socialization path including wide-range nationalization and increasing governmental control over prices and markets. In the late 70s severe problems showed up in terms of economic stagnation, the deterioration of physical infrastructure, and an increasingly overvalued exchange rate. Agricultural annual growth averaged 1 percent from 1976 to 1985, while agricultural exports were reduced by 50 percent in the same period (World Bank, 1991).

From 1985 an economic recovery program was launched. A key objective was to stimulate agriculture by increasing producer incentives. The program also emphasized the need for structural reforms in the financial sector, the reorganization of parastatals, and in the system of public administration. A number of governmental restrictions have been phased out since the mid 80s including a gradual elimination of price controls on outputs, credits, exchange rate and quantitative import controls. Input subsidies have been removed together with restrictions on traditional exports and the retention of export receipts (World Bank, 1996). More responsibility is given to the private sector both on the production side as well as on the marketing side. Today a multi-channel marketing system exists where private traders operate alongside governmental agencies. Reforms still in progress include a simplification of the tax structure, further privatization and liquidation of parastatals, and the promotion of private banking.[3]

The annual growth rate in agriculture was 5 % from 1991 to 1994, while the annual real export growth in agriculture was 4-5 percent during the same period.[4] The real exchange rate has experienced a substantial depreciation since the mid-1980s but has been more or less stable since 1993 (MOA, 1996). Debt overhang also represents a problem and the total external debt is equivalent to 200 percent of GDP. Debt service would absorb about half of the export earnings under existing terms. Another challenge is to undertake an effective tax reform in order to raise revenues that fall short of governmental expenditures. There are reasons to believe that restrictions on the supply side have been important for the low level of input consumption during the last 10 years. In spite of an increasing number of private stockists and marketing agents, there are still inefficiencies in the marketing system. This matters in particular for fertilizers and pesticides that have to be distributed over long distances. In some sectors there is still a mismatch between capacity and actual output.[5]

Agriculture is closely linked to the management of environmental resources. Tanzania, as most Sub-Saharan countries, is believed to face an increasing pressure on environmental resources, in spite of being a nation with rich resource endowments relative to population size. The problems gaining most attention are deforestation, soil erosion, and soil-mining processes, all believed to be strongly

[3] Many reforms still remain to be implemented especially in fiscal management, in the banking sector, and in public administration.

[4] There is considerable uncertainty associated with these figures. Weaknesses about the National Accounts of Tanzania are discussed in Bagachwa and Naho (1995).

[5] Supply constraints in Tanzania during the 70- and 80s are discussed in Lipumba et al. (1988) and Ndulu (1986).

interlinked with agricultural production decisions. Deforestation is believed to happen because of expanding agricultural frontiers and fuelwood extraction. Reliable figures on deforestation, however, are scarce and unreliable. Kulinda and Schechambo (1994) find that deforestation amounts to 520.000 hectares per year, with about half of this being regenerated. Mayawalla (1996) states that the annual deforestation equals 130.000 hectares. Soil erosion is considered a significant problem in specific areas, like the Kondo region, where losses of productive soils amounts to 1-2 mm per year and are the result of overgrazing and the cultivation of hillsides (Mbegu, 1994). An increasing number of studies identify soil-mining as the most significant environmental problem in southern Africa with soil nitrogen as the limiting soil nutrient (see e.g. Stoorvogel and Smaling, 1990). Tanzania, as well as some other sub-Saharan countries, is believed to move along a path of declining agricultural productivity, due to the losses of soil nutrients not being fully replaced by external sources such as chemical fertilizers. Such a development may constitute a hindrance for a future increase in agricultural production.

4. The model

The CGE model applied in this paper consists of two integrated submodels - an economic model and a soil model. The model (s) is static and as other models of this kind it can be thought of as a medium-term model reflecting the time markets need to reach a new equilibrium - but before major dynamic effects can take place. The model differs from "standard" CGE models in that the agricultural sector is quite disaggregated (12 crop producing sectors) and soil fertility is endogenous.[6] A complete description of the model is given in appendix A. The social accounting matrix (SAM) for our model is based upon the most recent figures available (1995).

Economic model

In the economic submodel, producers are profit maximizers and choose their levels of production and purchase their inputs on the basis of prices. On the supply side they decide whether to sell on the domestic market and/or to export. Domestic products and imports/exports are imperfect substitutes and the demand composition depends on relative prices. Households maximize utility and choose their levels of consumption based on income and prices. Some sectors like public consumption and public employment do not respond to prices. The economic model consists of 21 products and 23 goods. Sectors and goods coincide with the exception of the two imported inputs - fertilizer and pesticides. Fertilizers are applied in the six most important agricultural crop-producing sectors (coffee, cotton, tea, tobacco, maize and beans) while pesticides are applied in cotton, coffee and cashew. The remaining factors of production in agriculture are labor, capital, land area and nitrogen. Additional crop-producing sectors are banana, cassava, rice, other cereals, and other crops. The production sectors are livestock, forestry, food, textiles, electricity, transport and communication, construction, other manufacture, and other private services. Table 1 provides information on the assumptions made about

[6] See Appendix A for a full description of the model.

the crop-producing sectors. It follows that 7 sectors are exporting while 3 are importing. Production factor elasticities vary to some extent across sectors.[7] It is further noticed that for all food crop sectors, except maize, no real capital is present in agriculture.

Table 1: Technical assumptions about crop producing sectors.

Agricultural sectors	Export crop	Import crop	Elasticities Area	Capital	Labor	Nitrogen	Pesticides	Export [a]	Import [b]
Cash crops									
- Cotton	X		**0.011**	-	**0.86**	**0.08**[d]	**0.05**	0.9	-
- Coffee	X		**0.005**	**0.03**	**0.67**	**0.15**[d]	**0.14**	0.9	-
- Tea	X		**0.002**	**0.11**	**0.80**	**0.09**[d]	-	0.9	-
- Tobacco	X	X	**0.003**	**0.03**	**0.61**	**0.35**[d]	-	0.3	0.9
- Cashew	X		**0.008**	**0.04**	**0.81**	**0.10**	**0.04**	0.9	-
Food crops									
- Maize	(X)[c]		**0.007**	**0.03**	**0.75**	**0.21**[d]	-	0.9	-
- Rice		X	**0.002**	-	**0.96**	**0.04**	-		0.9
- Other crops	X	X	**0.004**	-	**0.95**	**0.04**	-	0.9	0.9
- Bananas			**0.002**	-	**0.98**	**0.02**	-	-	-
- Cassava			**0.010**	-	**0.93**	**0.06**	-	-	-
- Other Cereals			**0.006**	-	**0.95**	**0.04**	-	-	-
- Beans			**0.005**	-	**0.88**	**0.12**[d]	-	-	-

a) Elasticity of export substitution

b) Elasticitiy of import transformation

c) The parenthesis is to reflect that maize becomes an export crop in response to liberalization.

d) Crop producing sectors which apply chemical fertilizers.

The production function in all sectors are Cobb-Douglas, thus the elasticities in Table 1 are calculated on the basis of cost shares in the base year (1995). The calculation of the elasticity of nitrogen deserves additional attention. First, the average quantity of natural nitrogen for all crops is estimated on the basis of field studies. Second, the unit value of natural nitrogen is assumed to equal the market price of a similar unit of nitrogen provided by chemical fertilizers. Thus, the value of

[7] All elasticities in the production functions are calibrated to reproduce the base year figures while export and import elasticities are taken from other studies.

natural nitrogen can now easily be derived.[8] The cost share with respect to crop area is derived by applying the following procedure. First, land rent is calculated by attributing a certain part of gross profits in agricultural industries to land. Second, the value of natural nitrogen is subtracted from the land rent. It follows from Table 1 that this procedure has produced quite low land area elasticities. This finding supports opinions of nitrogen, rather than land area, being the scarce production factor in Tanzanian agriculture.

On the consumer side a Stone-Geary utility function is assumed which yields a linear expenditure system (LES) with a minimum basic consumption. The coefficients are calibrated from the SAM. The model allocates sectoral domestic output to domestic demand and exports, and domestic demand between domestic production and imports. The elasticities of export substitutions (CES) in exporting sectors and the elasticities of import transformation (CET) for importing sectors are all assumed constant and equal to 0.9. [9]

The model contains some structuralist features that reflect rigidities still present in the Tanzanian economy. All labor resources are not fully utilized and nominal wages are assumed fixed. An infinite elastic supply at a given wage rate seems more appropriate than a neo-classical clearing of the market.[10] However, it is chosen not to distinguish between skilled and unskilled labor. There is no explicit investment behavior in the model, capital is allocated in fixed proportions according to the base-year. Such an exogenous investment allocation rule is common in CGE-modeling (see e.g. de Janvry and Sadoulet, 1997; Robinson, 1989). Dynamic scenarios consist of year-by-year sequences of static equilibria based on the updating of the capital stock from the investment allocation rule. The

[8] For agricultural sectors applying chemical fertilizers, the value of fertilizer consumption is added with the value of natural nitrogen in order to arrive at elasticities of nitrogen. As a consequence institutional obstacles to fertilizer consumption in Tanzania are reflected in the magnitude of this elasticity.

[9] Price elasticities of supply in Tanzanian agriculture are presented in Mshomba (1989) and Dercon (1993). de Janvry and Sadoulet (1997) denote elasticities equal to 0.3 and 0.8 as low and medium-low substitutability, respectively.

[10] A labour market of this kind reflects short-run institutional constraints.

model applies a savings function specified by a constant savings ratio. The closure rule of the model is standard since total investments are determined by total savings.[11] The model contains an endogenous deficit of current account and an exogenous exchange rate to reflect a dirty float exchange rate management system. Private income is composed of wage earnings and profits in the private sectors. A constant share of private income is saved. Public saving is the sum of total tax income and public profits less exogenous expenditures. An important factor behind economic growth in this model is the assumptions made about Hicksian-neutral technological change (annual growth rate of 0.5 % for all industries).

Soil model

The soil module adopted into the CGE framework draws upon a work by Aune and Lal (1995) in which a tropical soil productivity calculator for Tanzania is developed. In this work nitrogen is the limiting soil fertility component in agriculture. Average crop output per hectare and available nitrogen (soil fertility) are the two variables that link the soil module with the economic model. Soil fertility is a factor of production in all crop-sectors and depends upon; i) the quantity of nitrogen coming from the use of chemical fertilizers, and ii) natural soil nitrogen. The two sources of nitrogen are considered as perfect substitutes in crop production in our model.

Natural soil nitrogen, being available for crop production in any year, is a function of three processes. The first is an exogenous source representing atmospheric nitrogen from rainwater.[12] The next two are more important and both are endogenous. First we have the decomposition of crop residues, left on the field after harvesting, that produces mineralized nitrogen. This supply is assumed to extend over three crop seasons and the quantity of mineralized nitrogen will depend positively on output per hectare in each sector, since higher outputs (more plant biomass) imply more crop residues and thus a higher future supply of nitrogen. Second, the production of mineralized nitrogen depends on the stock of soil organic matter present in the soil, which again releases a certain percentage of

[11] Investments can be determined by other factors than savings or assumed exogenous due to an active participation of the state in the investment program.

mineralized nitrogen every year.[13] In addition a share of annual crop residues also adds to the stock of soil organic matter.

The use of chemical fertilizers has an immediate - and a long-term effect on soil fertility. First, agricultural outputs increase with fertilizer use. Second, higher outputs raise the quantity of crop residues, this way providing soils with additional nutrients in future periods. In addition, higher outputs have a direct effect on soil erosion, since more output per hectare (more plant biomass) provides soils with a better cover against erratic attacks from wind and rain and a better root structure (cover factor). The soil calculator, however, is not able to incorporate all factors that may influence soil depth changes such as cultivation timing decisions, plowing techniques and the use of soil conservation measures (see Grepperud, 1997). As a consequence, erosion in our model varies as a result of changes in vegetation cover, only.

Soil-nutrient cycles are modeled for most crop-producing sectors. The parameter values for each crop are based on Tanzanian field studies each having a different impact on soil mining and soil erosion (Aune and Lal, 1995). Perennials like coffee are less erosive than annual crops like maize. Soil fertility is assumed exogenous for cashew since phosphorous is believed to be the limiting soil nutrient for this crop. It also is assumed that soil erosion is independent of outputs in tea production (no cover effect). The land area devoted to each crop is endogenous with the exception of coffee and tobacco. Land already cultivated is assumed to be most fertile.[14] The dynamics of the soil model consists of year by year sequences of static equilibria based on the updating of the stock of soil organic matter and soil depth. Since crops differ with respect to their effects on the soil- base, changes in crop patterns over time will influence soil-nitrogen cycles and thus have economy-wide ramifications.

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[12] By natural soil nitrogen is meant mineralised nitrogen which becomes available for plants.

[13] Some nitrogen in the soil organic matter is lost due to leaching and soil erosion (the removal of top soil layer).

[14] Which seems to be a fairly good description of most areas in Tanzania (for some areas in the southern highlands this is not necessarily the case).

5. Policy simulation results

In this section the results are presented. The endogenous variables that we focus upon are production, input use, trade, indicators of self-sufficiency, and variables that measure environmental consequences. Each of the two scenarios is contrasted to a common reference scenario. The agricultural sector (all crop producing sectors) constitutes 36% of GDP in the base year of the model (1995) while non-agricultural sectors represent the residual part. Non-agriculture includes food processing and animal production in addition to industry and services. Cash crops and food crops represent 17% and 83% of agricultural GDP, respectively. Maize is the single most important crop representing about 22% of agricultural outputs. Figures that describe the reference scenario are presented in Table 2. It follows that the share of agricultural to total production (in constant prices), along the reference scenario, is gradually declining over time. The annual growth rate in the economy in 1996 is about 5% but becomes lower over time. The average annual growth rate in agriculture for the 1995-2000 period is 3.8% and falls below 2%. the next 10 years. One reason for this is that fertilizer consumption is not growing rapid enough to prevent the average soil productivity (available nitrogen) from declining along the reference scenario.

In scenario A we analyze the consequences of introducing fertilizers subsidies from 1996 and throughout the model horizon. For the time being there is no domestic production of chemical fertilizers in Tanzania and thus all fertilizers are imports. Imports in Tanzania are levied taxes, consequently, a natural way to portray a subsidy in our model is to lower the import-tax rate on fertilizers. In this study, the tax-rate on the value of imported fertilizers, is reduced from 15% to 7%. Such a reduction will, *ceteris paribus*, reduces total import-tax revenues in 1996 about 3%.

Scenario B represents the maize trade liberalization. The barring of export in the reference scenario implies that maize export is exogenous and equal to zero (non-traded good). However, illegal exports of maize constitute about 5% of the annual production of maize. As a consequence, we have chosen to calibrate an export price on maize in the reference scenario that produces the observed illegal export share.[15] The reference scenario also assumes a low elasticity of export transformation (0.3).[16] A maize trade liberalization will now be interpreted as a positive shift in the export price together with a higher elasticity of export transformation (0.9). Reliable estimates on the average increase in the Tanzanian maize export-price, from a trade liberalization, are difficult to find. However, some information on maize price differentials between Tanzania and Kenya is available in Lele et al., (1989). Applying purchasing power parities, producer prices were found to be 50-100% higher in Kenya in the period 1983-87. However, regulation on domestic food grains (distribution and trading) in Tanzania was lifted in 1987, and in 1990 the government decontrolled producer prices for all food crops which implied that cereal prices became indicative for the first time. Precise estimates for producer prices following the reforms of 1987 and 1990 are not available. In this analysis it is assumed that the export price will increase by 20% as a consequence of the lifting of the barriers to maize export. We find it likely that maize, given a trade liberalization, will be treated in the same way as other export crops, hence a positive export-tax rate on maize is assumed to equal the rate that applies for traditional export crops.

Table 2: Reference scenario. Average annual growth. 1995 to 2000 and 2001 to 2010.

Activities	Reference scenario *1995-2000*	Reference scenario *2001-2010*
GDP	3.8	1.8
- Agriculture	1.8	0.8
- Non agriculture	5.3	2.5
Input use		
- Labor	1.3	0.4
- Fertilizer	4.6	2.5
- Land use	3.2	2.4
Trade		
- Export	6.6	2.7
- Import	2.7	1.3

[15] For estimates on illegal cross-border trade see Ackello-Oguto and Echessah (1997) and MOA/SUA (1997).

[16] This assumption seems reasonable in view of the illegal character of maize export.

It follows from the above presentation that both policy reforms are interpreted as short-term strategies in our model analysis - no governmental long-term investments are assumed necessary to support them. The supply of modern inputs during the 80s was mainly conducted by governmental parastatals. During this period bottlenecks on the supply side were more decisive for fertilizer consumption than prices. This situation has changed gradually during the last 5 years due to privatization, especially in the southern highlands, but there is still some way to go. Hence, the success of both policies will also depend on future investments in transport and marketing.

Before presenting the main results arrived at from the policy simulations, we will contrast the economic development in the reference scenario, with the same scenario now without the soil submodel. Disconnecting the soil submodel makes natural soil fertility to become a constant in the agricultural production functions. From Figure 1 it is seen that GDP in constant prices is 2% higher after 18 years (2013) without a soil submodel. This finding shows, that a "traditional" model (constant soil fertility) tends to overshoot relative to a model that includes a soil model. Chemical fertilizer consumption at prevailing prices is not able to prevent agricultural sectors from harvesting

Figure 1: GDP at constant 1995 prices. Reference scenario with and without soil submodel.

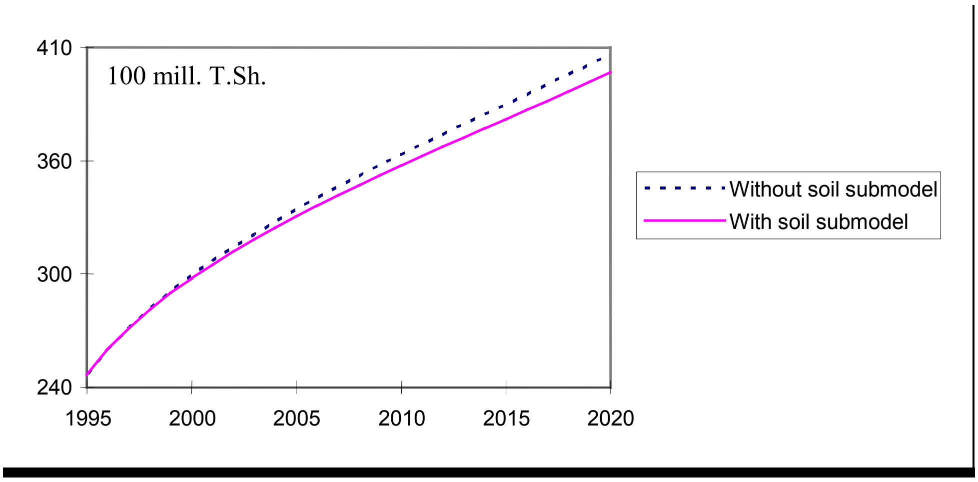
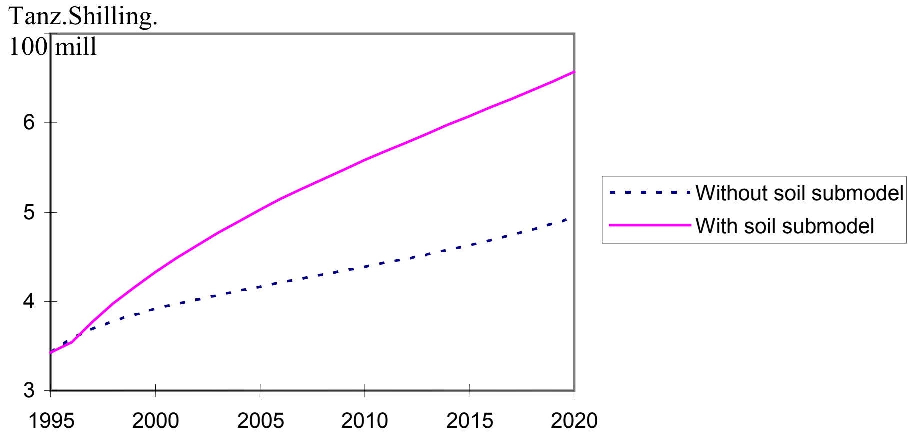


Figure 2: Fertilizer consumption at constant 1995 prices.

Reference scenario with and without soilmodel.



soil nutrients at a higher rate than their replacement, in spite of land use and fertilizer consumption being significantly higher, when the soil submodel is included. This is confirmed by Figure 2 where the development in fertilizer consumption across the two scenarios is compared. In year 2010 fertilizer consumption is about 30% higher in the model with endogenous soil fertility.

In Table 3 the main results from the two policy simulations are presented. It follows that the economic impacts that arise from a fertilizer subsidy are in general more significant than those following from a maize trade liberalization. The increase in the economic activity, as measured by GDP in constant prices, is 4-5 times stronger in percentage points for the fertilizer subsidy. A fertilizer subsidy (scenario A) increases the GDP level in year 2000 and year 2010 by 5.3% and 7.2% as compared to the reference scenario. The increase in GDP level that follows from the maize-trade liberalization (scenario B) at the same two dates is only 1.2% and 1.5%, respectively.[17] Furthermore, fertilizer subsidies tend to strengthen the agricultural sector relatively more than the non-agricultural sector, while the opposite tendency matters for a maize trade liberalisation. Thus, the maize producing sector in Tanzania seems too have strong non-agricultural complementarities.

[17] The effects arising from a maize trade liberalisation turned out to be quite sensitive to upward adjustments of the elasticity of export transformation for maize.

The consequences for input use vary across the two reforms. This becomes evident if we compare changes in input demand relatively to changes in agricultural GDP for each policy reform. For scenario A, the increase in demand for fertilizer in percentage points is significantly higher than the increase in percentage points for agricultural production. For scenario B, the same comparison yields relatively less deviation. The total use of labor increases more or less proportionally to the change in the economic activity (GDP) in both scenarios. As concerning land use relatively to agricultural GDP growth, however, the two scenarios differ. A trade reform speeds up the rate at which new lands are devoted to crop production, in spite of a relatively weak impact on agriculture outputs. For a fertilizer subsidy the opposite tendency is observed. A fertilizer subsidy (Scenario A) increases the export of all traditional cash crops like coffee, tea, and tobacco as well as imports of modern inputs (fertilizer and pesticides). The share of fertilizer import to total imports in this scenario is 18% in year 2010, while the same ratio in scenario B is 4%. The export of maize, however, is 25% higher in scenario B in year 2000 as compared to the baseline scenario. Imports to all sectors, relatively to the reference scenario, increase more or less proportional to output for both scenarios.

The impact on GDP, for each of the two scenarios relatively to the baseline scenario, is quite different in magnitude. This finding is somewhat surprising in view of maize being the single most important crop in Tanzania. However, a fertilizer subsidy will, in contrast to a maize trade liberalization, increase the overall profitability in agriculture. Higher profitability raises private incomes, economic activity, exports and imports, and thus public revenues and savings. However, one would expect that fertilizer subsidies (a lowering of the tax-import rate) would also introduce contractive effects due to the lowering of tax revenues. From Table 3 it follows that this is not the case. The immediate decline in revenues that follows from a tax-rate reduction, is in fact offset by higher fertilizer imports and higher agricultural production.[18] A factor of importance is that a fertilizer subsidy will reduce efficiency losses in the economy since the subsidy, as interpreted in this analysis, yields a reduction in the import-tax rate on fertilizers.

[18] The most important source to higher governmental revenues given a maize trade liberalisation are production tax- and export tax revenues on maize.

Both policy reforms have also been contrasted to model versions where the soil model is absent, in order to investigate what the implications are from incorporating soil-nutrient cycles. A first conclusion is now that all expansive effects are weakened in both scenarios (A and B). Hence, the inclusion of soil-nutrient cycles makes agricultural policy reforms relatively more attractive. An important reason for this conclusion is that agricultural outputs are strictly concave in available nitrogen. In a model with declining soil nitrogen, the marginal productivity of additional soil nitrogen will be higher relatively to the models where soil fertility is constant. A second conclusion is that a fertilizer subsidy becomes relatively less expansive, relatively to a maize trade liberalization, when soil-nutrient cycles are ignored.

Table 3: Simulation results. Percentage deviation from the reference scenario in year 2000 and 2010.

Activities	Fertilizer subsidies (A) *2000*	Fertilizer subsidies (A) *2010*	Maize trade liberalisation (B) *2000*	Maize trade liberalisation (B) *2010*
GDP	5.3 %	7.2 %	1.2 %	1.5 %
- Agriculture	5.7 %	7.9 %	1.0 %	1.3 %
- Non agriculture	5.0 %	6.7 %	1.3 %	1.6 %
Input use				
- Labor	5.6 %	7.6 %	1.3 %	1.6 %
- Fertilizer	21.3 %	23.8 %	2.0 %	2.4 %
- Land use	2.4 %	3.3 %	1.4 %	1.9 %
Trade				
- Export	11.9 %	14.2 %	1.7 %	2.0 %
- Import	5.7 %	7.5 %	1.2 %	1.5 %
Governmental revenue	5.2%	6.8%	1.6 %	1.9 %
Sufficiency indicators				
- Consumer price of maize	- 0.4 %	-1.5 %	- 0.3 %	-1.4 %
- Maize Consum.	2.0 %	2.9 %	0.9 %	1.1 %
- Ratio of domestic production to consumption[a].	0.0%	- 0.02 %	0.0 %	-0.02 %
Environmental variables				
- Soil depth (cm)	0.0%	0.0%	0.0%	0.0%
- Nitrogen	7.0 %	7.4 %	- 0.1 %	-0.1 %

a) This ratio is calculated only for food crops that are both imported and consumed at home.

One objection to the promotion of maize trade in Tanzania has been the concern about food security and food self-sufficiency. Some information on possible distributive consequences can be attained in this analysis by looking at production and consumption figures for the most important staple crop in Tanzania, maize. The consumption of maize increases in both scenarios (A and B) as compared to the reference scenario (see Table 3). However, the development in the ratio of domestic production to domestic consumption for food crops (all being both imported and produced domestically) does not change significantly, in either policy reform, as compared to the reference scenario. Fertilizer subsidies are being accused of having negative distributive consequences, since cash crop production is believed to be conducted (primarily) by well-endowed farmers. However, household surveys reporting on fertilizer consumption patterns do not support such views. Forty percent of farmers above the poverty line use chemical fertilizers, while 30 percent below the poverty line do (NSCA, 1996). «The distribution of all farmers who use fertilizer is heavily weighted towards the smaller holdings» (World Bank, 1994, p.75). This fact is due to the priority the government has given to fertilizer consumption during the last decades (in particular to the maize producing regions in the southern highlands). In spite of the dual character of Tanzanian agriculture a fertilizer subsidy need not discriminate smallholders at the expense of cash crop producing estates.

Natural soil nitrogen (available nitrogen per hectare of cultivated land from other sources than chemical fertilizers) increases strongly, compared to the reference scenario, for Scenario A (fertilizer subsidy), while a rather small decline is observed for scenario B (trade liberalization). The increase observed for Scenario A is due to the strengthening of soil-nutrient cycles that follows from higher fertilizer consumption. More nutrients will over time be recycled to the soil, due to a higher production of crop residues. In this analysis we expected a maize trade liberalization to accelerate soil erosion processes (very erosive crop), and the same processes to be weakened for a fertilizer subsidy (soil cover effect). However, from Table 3, it follows that there are no detectable differences. This, rather surprising, result suggests that there are no environmental drawbacks in terms of soil erosion associated with maize trade liberalization.[19] One reason for this finding is that most of the agricultural production in Tanzania, so far, has occurred on flat lands where erosion is less of a problem. This feature is reflected in the values of the soil model parameters describing relationships between crop production and erosion. The most severe environmental effect identified in our analysis seems to be the land extensive processes triggered by a maize trade liberalization. Our results suggest that the area devoted to agricultural production will be about 2% higher by the year 2010 relative to the baseline scenario. Such an increase represents 150.000 additional hectares of land and may constitute a threat to Tanzanian natural forest reserves and savannas.

The results arrived at for crop-producing sectors are presented in Table 4. It is observed that fertilizer subsidies promote cash crops relatively to food crops, while for maize liberalization the opposite occurs. The production of cash crop and food crops increases by 23.8% and 3.2%, respectively, compared to the reference scenario in year 2010 given a fertilizer subsidy. The same figures for maize trade liberalization are 1.1% and 1.4% in year 2010. It is further noticed that fertilizer subsidies increase the production of coffee significantly, but also strengthens the production of tobacco, while the increase in food crop production (including maize) is smaller.

Table 4. Simulation results. Percentage deviation in agricultural production, relative to the baseline scenario, across sectors. Years 2000 and 2010.

	Fertilizer subsidies(A)	**Fertilizer subsidies(A)**	**Maize trade liberalization (B)**	**Maize trade Liberalization (B)**
	2000	***2010***	***2000***	***2010***
Cash crops	19.9	23.8	0.7	1.1
- Cotton	10.9	15.3	0.8	1.2
- Coffee	44.6	46.9	0.0	0.5
- Tea	7.6	9.9	1.1	1.5
- Tobacco	23.5	30.2	1.5	1.7
- Cashew	4.9	6.5	0.9	1.2
Food crops	2.2	3.2	1.1	1.4
- Cassava	1.0	1.3	0.2	0.2

[19] One explanation could be that erosion processes occur very slowly over time so that a longer horizon is needed to detect any differences.

- Maize	2.1	3.0	2.3	3.1
- Rice	1.8	2.5	0.5	0.6
- Other cereals	1.7	2.5	0.4	0.6
- Beans	1.6	2.4	0.3	0.5
- Bananas	1.9	2.5	0.5	0.6
- Other crops	3.3	4.7	0.8	1.1

6. Conclusions

In this paper two policy proposals, both discussed in the literature on Tanzania, are analyzed by means of a CGE model which is considered an effective tool for evaluating policy packages according to multiple criteria. Our ambition has been to conduct a more precise analysis of the policy proposals as compared to former discussions on the subject. However, Tanzania is in a transitional phase, moving rapidly from a state with heavy governmental intervention to private sector decision-making. Thus it becomes demanding to develop a CGE model capturing all rigidities still present in the economy. As a consequence, the conclusions arrived at must be interpreted with care. In our analysis we have assumed a Keynesian labor market and a capital market where investments are not allocated according to relative profitability but to observed shares in the base year. In addition, an exogenous exchange rate is assumed, an assumption that minimizes the negative consequences that may arise from government deficits. Finally, the two policy reforms are interpreted as short-term measures, in that no investments in marketing and infrastructure are needed to support the reforms.

Our model simulations suggest that current fertilizer consumption rates in Tanzania are not sufficiently high to keep up current agricultural growth rates into the future. A high positive growth rate can only be sustained by increasing the future consumption of fertilizers. Furthermore, treating soil fertility as an endogenous factor of production is found to make agricultural policy reforms relatively more advantageous (more expansive) relatively to "standard" CGE approaches. The results arrived at for the two policy reforms are not readily comparable since the budgetary implications are very different across the two reforms. However, *ceteris paribus*, budget effects should favor the lifting of maize trade regulations, since such a policy, in contrast to input subsidies, has positive macro economic effects at no budgetary costs (or positive given an export-tax rate). Our analysis also points to other considerations that may be of importance to policymakers. First, a maize trade reform, in contrast to a fertilizer subsidy, will strengthen agricultural sectors relatively more than non-agricultural sectors. Second, a maize reform, in contrast to a fertilizer subsidy, promotes food crop production relatively to cash crop production. Third, both reforms have no significant effect on soil erosion processes - a rather surprising result in view of ex-ante expectations. However, a maize reform induces land extensive processes, while a fertilizer subsidy promotes land-intensive agriculture. Thus, the serious environmental concern in Tanzania, seems to be the pushing of the agricultural frontier onto natural forest reserves, a process induced by a maize trade liberalization.

A maize trade liberalization combined with a positive export-tax, seems to increase public revenues which again may be applied to promote distributive objectives. At the same time, our analysis shows that the budgetary implications from a fertilizer subsidy, interpreted as a reduction in the fertilizer import-tax, need not be adverse for two reasons. First, fertilizer imports increase because of lower farm gate input prices – an effect that modifies the negative revenue effect. Second, a lower import-tax rate also reduces efficiency losses in the economy, which again increase the overall activity, thus creating revenues. In addition, Tanzanian household surveys indicate that a fertilizer subsidy need not give priority to well-endowed farmers in Tanzania.

References

Ackello-Ogutu, C. and Echessah, P.N. 1997. "Unrecorded cross-border trade between Tanzania and her neighbors: Indications for food security." Draft report. Regional Economic Development Support (REDSO/ESA) and USAID.

Alfsen, K.H, de Franco, M.A., Glomsrød, S. and Johnsen, T. 1996. "The cost of soil erosion in Nicaragua." *Ecological Economics*, Vol. 16: 129-145.

Alfsen, K.H. Bye, T., Glomsrød S. and Wiig, H. 1997. "Soil degradation and economic development in Ghana." *Environment and Development Economics,* Vol. 2: 119-143.

Aune, J.B. and Lal, R. 1995. "The tropical soil productivity calculator - a model for assessing effects of soil management on productivity", in R. Lal and B.A. Stewart (eds.): *Soil management: Experimental basis for sustainability and environmental quality,* III series: Advances in soil science, Boca Raton. Florida, CRC press.

Bagachwa, M.S.D. and Naho, A. 1995. "Estimating the second economy in Tanzania." *World Development*, Vol.23, No.8: 1387-1399.

Barker, R. and Hayami, Y. 1976. "Price support versus input subsidy for food self-sufficiency in developing countries." *American Journal of Agricultural Economics*, Vol. 58 (November): 617-628.

Binswanger, H. 1990. "The policy response of agriculture". Proceedings of the World Bank Annual Conference on Development Economics 1989.

Coulter, J. and Lele, U. 1993. "The Kilimo-Sasakawa global 2000 project in Tanzania: A mid-term evaluation report." Mimeo. Atlanta: The Carter Center.

de Janvry, A. and Sadoulet, E 1997. "Agricultural price policy in general equilibrium models: Results and comparisons." *American Journal of Agricultural Economics,* Vol. (May*):* 230-245.

Dercon, S. 1993. "Peasant supply response and macroeconomic policies: Cotton in Tanzania." *Journal of African Economies*, Vol.2, No.2: 157-194.

FAO 1996. Fertilizer yearbook 1996, Rome.

Glomsrød, S. Monge, M.A. and Vennemo, H. 1997. "Structural adjustment and deforestation in Nicaragua." Discussion Papers 193, Statistics Norway, Research Department.

Grepperud, S. 1997. "The impact on farm conservation policies in developing countries: What can be learned from theory?" *Quarterly Journal of International Agriculture,* Vol.1: 41-57.

Hansen, S. 1990. "Macroeconomic policies and sustainable development in the third world." *Journal of International Development*, Vol.2, No.2. (October): 533-557.

Holden, S.T. and Shanmugaratnam, S. 1994. "Structural adjustment, production subsidies and sustainable land use." Discussion Paper No. 11. Agricultural University of Norway. Department of Economics and Social sciences.

Hwa, E. 1983. "The contribution of agriculture to economic growth." World Bank Staff Paper No. 619 Washington D.C., The World Bank.

Kesseba, A.M. 1989. "Food shortage and sustainable development" in: Proceedings of the Symposium on the Sustainability of agricultural production systems in sub-Saharan Africa, September 4-7, 1989. Aas, Norway. NORAGRIC Occasional Papers series C: Development and environment No.4. NORAGRIC, Agricultural University of Norway, Aas.

Kulinda, K. and Schechambo, S. 1994. "Structural adjustment, energy use and the environment. Some evidence from rural Tanzania." Paper presented at the Ninth Economic Policy Workshop. Dar Es Salaam. November, 28/30 1994.

Lal, R. 1993. "Technological options towards sustainable agriculture for different ecological regions of sub-Saharan Africa." In: Technologies for Sustainable Agriculture in the Tropics, ASA special publication 56: 295-308.

Lele, U., Christiansen.R.E. and Kadiresan, K. 1989. "Fertilizer policy in Africa. Lessons from development programs and adjustment lending. 1970-87." MADIA Discussion Paper No.5. The World Bank, Washington D.C.

Lipumba, N., Ndulu, B., Horton, S. and Plourde, A. 1988. "A supply constrained macroeconometric model of Tanzania." *Economic Modeling*, (October): 354-376.

Mayawalla, A.E.J. 1996. "Structural adjustment policies and the management of soil and forest resources in Tanzania." in Christansson, C. and Kikula, I.S. (eds.) *Changing Environments: Research on Man-Land Interrelations in Semi -Arid Tanzania.*

Mbegu, A.C. 1994. "The problems of soil erosion and rehabilitation: Lessons from the HADO-project." Paper presented at the Workshop on Man-Land Relationships, Dodoma, (February): 13-18.

MOA 1996. "The Rolling plan and forward budget for Tanzania for the period 1996/97-1998/99." Ministry of Finance and The president Office Planning Comission. Volume I.

MOA/SUA 1997. "Analysis of the comparative economic advantage of alternative agricultural production options in Tanzania: A draft report." Livestock Development and Cooperatives, Ministry of Agriculture (MOA), and Department of Agricultural Economics and Agribusiness, Sokoine University of Agriculture (SUA).

Mshomba, R.E. 1989. “Price elasticity of supply of Tanzania’s major export crops.” *Eastern African Economic Review*, Vol.5, No.1 (June): 9-23.

Ndulu, B.J. (1986) “Investment, output growth and capacity utilization in an African economy: The case of manufacturing sector in Tanzania.” *Eastern Africa Economic Review*, Vol. 2, No.1: 14-30.

NSCA 1996. “National Sample Census of Agriculture 1994/95.” Tanzania Mainland. Vol. II. Technical and Operational Report. Bureau of Statistics, Planning Commission.

Persson, A. and Munasinghe, M. 1995. “Natural resource management and economy wide policies in Costa Rica: A computable general equilibrium (CGE) modeling approach.” *The World Bank Economic Review*, Vol. 9, No.2 : 259-285.

Putterman, L. 1995. “Economic reform and smallholder agriculture in Tanzania: A discussion of recent market liberalization, road rehabilitation, and technology dissemination efforts.” *World Development,* Vol.23, No.2: 311-326

Rao, J.M. 1989. “Aricultural supply response: A survey.” *Agricultural Economics* Vol.3: 1-22.

Rao, J.M. and Caballero J.M. 1990. “Agricultural performance and development strategy: Retrospect and prospect.” *World Development*, Vol.18, No.6: 899-913.

Reardon, T. 1989. “Issues of sustainability in agricultural research in Africa.” in *Proceedings of the Symposium on the Sustainability of agricultural production systems in Sub-Saharan Africa,* September 4-7, 1989 Aas, Norway. NORAGRIC Occasional Papers Series C: Development and Environment No.4. NORAGRIC, Agricultural University of Norway, As.

Repetto, R. 1987. “Economic incentives for sustainable production.” in Annals of Regional Science, Special Edition, Environment Management and Economic Development, Vol. 21, No. 3 (November).

Robinson, S. 1989. “Multisectoral models.” In: H. Chenery and T.N. Srinivasan, eds, Handbook of Development Economics, Vol.2, Amsterdam. Elsevier Science Publishers BV.

Singer. P. 1982. “Success stories of the 1970s: Some correlations.” World Development, Vol.12: 951-952.

Stoorvogel, J.J. and Smaling, E.M.A. 1990. “Assessment of soil nutrient depletion in sub-Saharan Africa.” Report 28, Vol. I, The Winand Staring Centre, Wageningen, Holland.

Unemo, L. 1993. “Environmental impact of governmental policies and external shocks in Botswana: A CGE-model approach.” Beijer Discussion Paper Series 26. Beijer institute, Stockholm, Sweden.

World Bank 1991. “Tanzania. Towards sustainable development in the 1990s.” World Bank Report No. 9352/TA.

World Bank 1994. “Tanzania Agriculture Sector Memorandum.” Vol. II, Report No. 12294/TA. Agriculture and Environment Operations Division, Eastern African Department, Africa region.

World Bank 1996. “Tanzania. The challenge of reforms: Growth, incomes and welfare.” Vol. I, Report No. 14982/TA. Country Operations Division. Eastern Africa Department. Africa Region.

APPENDIX: MODEL DESCRIPTION AND LIST OF VARIABLES

A. The economic model

No.	Name	Equations	sectors goods
1.	Prodag1	$X_i = tech_i \cdot bb_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta_i} \cdot N_i^{\gamma_i} \cdot PA_i^{\chi_i} \cdot KL_i^{\mu}$	i=AG1
2.	Prodag2	$X_i = tech_i \cdot bb_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta_i} \cdot N_i^{\gamma_i} \cdot PA_i^{\chi_i} \cdot kl_i^{\mu}$	i=AG2
3.	Prodind	$X_i = tech_i \cdot bb_i \cdot L_i^{\alpha_i} \cdot kk_i^{\beta_i}$	i=IND
4.	Nitroland1	$LN_i = \Omega_i \cdot NR_i \cdot KL_i$	i=AG1
5.	Nitroland2	$LN_i = \Omega_i \cdot NR_i \cdot kl_i$	i=AG2
6.	Nitrogen	$N_i = F_i + LN_I$	
7.	Demlab	$\mathrm{w} \cdot \mathrm{L_i} = \alpha_i \cdot \mathrm{X_i} \cdot \left(\mathrm{P_i} - \sum_j \mathrm{PC_j} \cdot \left(1 + \mathrm{ta_{ji}}\right) \cdot \mathrm{a_{ji}} \right)$	i=Z j=J
8.	Dempes	$PC_{pes} \cdot (1 + ta_{pes,i}) \cdot PA_i = \chi_i \cdot X_i \cdot \left(P_i - \sum_j PC_j \cdot \left(1 + ta_{ji}\right) \cdot a_{ji} \right)$	i=AG j=J
9.	Demfer	$PC_{fer} \cdot (1 + ta_{fer,i}) \cdot N_i = \gamma_i \cdot X_i \cdot \left(P_i - \sum_j PC_j \cdot \left(1 + ta_{ji}\right) \cdot a_{ji} \right)$	i=AG j=J
10.	Demland1	$\mathrm{KL_i} = \dfrac{\mu_i}{\left[\left(\mathrm{PC_{fer}} \cdot NR_i \left(\dfrac{\mathrm{exxs}}{\mathrm{phis}} \right) + pkl_i \right) - \left(\mathrm{P} - \Sigma\, \mathrm{a_{ij}} \mathrm{PC_j} \cdot (1 + \mathrm{ta_{ij}}) \right) \cdot \mathrm{X_i} \cdot \dfrac{\gamma_i \cdot NR_i \cdot exxs}{phis \cdot N_i} \right]}$.	i=AG1
11.	Demland2	$kl_i = \dfrac{\mu_i}{\left[\left(\mathrm{PC_{fer}} \cdot NR_i \left(\dfrac{\mathrm{exxs}}{\mathrm{phis}} \right) + PKL_i \right) - \left(\mathrm{P} - \Sigma\, \mathrm{a_{ij}} \mathrm{PC_j} \cdot (1 + \mathrm{ta_{ij}}) \right) \cdot \mathrm{X_i} \cdot \dfrac{\gamma \cdot NR_i \cdot exxs}{phis \cdot N_i} \right]}$.	i=AG2
12.	Pricomp1	$\mathrm{PC_i} \cdot \mathrm{XC_i} = (1 + \mathrm{td_i}) \cdot \mathrm{PD_i} \cdot \mathrm{XD_i}$	i=NIM
13.	Pricomp2	$\mathrm{PC_i} \cdot \mathrm{XC_i} = (1 + \mathrm{td_i}) \cdot \mathrm{PD_i} \cdot \mathrm{XD_i} + \mathrm{pm_i} \cdot (1 + \mathrm{tm_i}) \cdot \mathrm{MM_i}$	i=IM1
14.	Pricomp3	$PC_i \,.\, XC_i = (1 + tm_i) \,.\, pm_i \,.\, MM_i$	i=pes, fer
15.	Compagg1	$\mathrm{XC_i} = \mathrm{XD_i}$	i=NIM
16.	Compagg2	$\mathrm{XC_i} = \mathrm{qq_i} \cdot \left[\mathrm{q_i} \cdot \mathrm{MM_i^{-\tau}} + (1 - \mathrm{q_i}) \cdot \mathrm{XD_i^{-\tau}} \right]^{\frac{-1}{\tau}}$	i=IM1
17.	Compagg3	$XC_i = MM_i$	i=pes, fer

18.	Demimp	$\frac{MM_i}{XD_i}=\left[\frac{PD_i\cdot(1+td_i)}{pm_i\cdot(1+tm_i)}\cdot\frac{q_i}{1-q_i}\right]^{\frac{1}{1+\tau}}$	i=IM1
19.	Valsale1	$P_i\cdot X_i=PD_i\cdot XD_i$	i=NEX
20.	Valsale2	$P_i\cdot X_i=PD_i\cdot XD_i+pe_i\cdot EE_i$	i=EX
21.	Allgood1	$X_i=XD_i$	i=NEX
22.	Allgood2	$X_i=hh_i\cdot\left[h_i\cdot EE_i^{\rho}+(1-h_i)\cdot XD_i^{\rho}\right]^{\frac{1}{\rho}}$	i=EX
23.	Suppex	$\frac{EE_i}{XD_i}=\left[\frac{pe_i}{PD_i}\cdot\frac{1-h_i}{h_i}\right]^{\frac{1}{\rho-1}}$	i=EX
24.	Profitt1	$PRFT_i=X_i\cdot\left[P_i-\sum_j a_{ji}\cdot PC_j\cdot\left(1+ta_j\right)\right]-w\cdot L_i-$ $PC_{pes}\cdot(1+ta_{pes})\cdot PA_i-PC_{fer}\cdot(1+ta_{fer})\cdot F_i$	i=AG j=J
25.	Profitt2	$PRFT_i=X_i\cdot\left[P_i-\sum_j a_{ji}\cdot PC_j\cdot\left(1+ta_j\right)\right]-w\cdot L_i$	i=IND j=J
26.	Income	$Y=\sum_i(w\cdot L_i+PRFT_i)+w\cdot lg$	i=Z
27.	Expendd	$EXPEND=c\cdot(1-ty)\cdot Y$	
28.	Privcons	$PC_i\cdot CD_i=PC_i\cdot\theta_i+\kappa_i\cdot\left[EXPEND-\sum_j PC_j\cdot\theta_j\right]$	i=J j=J
29.	Govrev	$GR=ty\cdot Y+\sum_j td_j\cdot PD_j\cdot XD_j+\sum_l te_l\cdot PE_l\cdot EE_l+$ $\sum_i tm_i\cdot pm_i\cdot MM_i+\sum_k ta_{pes}\cdot PC_{pes}\cdot PA_k+$ $\sum_k ta_{fer}\cdot PC_{fer}\cdot F_k+\sum_n\sum_j ta_n\cdot PC_n\cdot a_{nj}\cdot X_j$	j=Z l=EX i=IM k=AG n=J
30.	Govsav	$SGOV=GR-\sum_i PC_i\cdot gc_i-w\cdot lg$	i=J
31.	Totinv	$JJ=(1-c)\cdot(1-ty)\cdot Y+SGOV-\sum_i PC_i\cdot cs_i-er\cdot sfor$	i=J
32.	Invgood	$PC_j\cdot DK_{ji}=imat_{ji}\cdot kshare_i\cdot JJ$	i=I1 j=I2
33.	Eqcomp1	$XC_i=\sum_j a_{ij}\cdot X_j+cs_i+gc_i+CD_i$	i=I3 j=Z
34.	Eqcomp2	$XC_i=\sum_j a_{ij}\cdot X_j+cs_i+gc_i+CD_i+\sum_l DK_{il}$	i=I2 l=I1
35.	Eqcomp3	$XC_i=\sum_k PA_k+\sum_j a_{ij}\cdot X_j+cs_i+gc_i+CD_i$	i=pes j=Z k=AG

36.	Eqcomp4	$XC_i = \sum_k F_k + \sum_j a_{ij} \cdot X_j + cs_i + gc_i + CD_i$	i=fer j=Z k=AG

B. The soil model

37.	$NR_i = rns \cdot NS_i + \frac{\lambda_i}{3} \cdot \sum_{s=2}^{4} NRR_{i,t-s} + nas_i$	i=AG
38.	$NS_i = (1 - rns) \cdot NS_{i,t-1} + (1 - \lambda_i) \cdot NRR_{i,t-1} - NE_{i,t-1}$	i=AG
39.	$NRR_i = \frac{X_i}{KL_i} \cdot \left(retain_i \cdot ncss_i \cdot \frac{1 - hs_i}{hs_i} + ncrs_i \cdot \frac{1}{hs_i \cdot srs_i} \right)$	i=AG1
40.	$NRR_i = \frac{X_i}{kl_i} \cdot \left(retain_i \cdot ncss_i \cdot \frac{1 - hs_i}{hs_i} + ncrs_i \cdot \frac{1}{hs_i \cdot srs_i} \right)$	i=AG2
41.	$NE_i = rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot ms_i \cdot \frac{cpa_i \cdot NS_i}{bds_i \cdot 10 \cdot D_i} \cdot$	i=AG3
42.	$NE_i = rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot ms_i \cdot \frac{NS_i}{bds_i \cdot 10 \cdot D_i} \cdot \left(cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{KL_i} \right)$	i=AG4
43.	$NE_i = rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot ms_i \cdot \frac{NS_i}{bds_i \cdot 10 \cdot D_i} \cdot \left(cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{kl_i} \right)$	i=AG5
44.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot cpa_i}{bds_i \cdot 10}$	i=AG3
45.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot \left(cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{KL_i} \right)}{bds_i \cdot 10}$	i=AG4
46.	$D_i = D_{i,t-1} - \frac{rs_i \cdot ks_i \cdot ss_i \cdot ws_i \cdot \left(cp_i - cpars_i \cdot exxs_i \cdot \frac{X_i}{kl_i} \right)}{bds_i \cdot 10}$	i=AG5

C. List of good and sectors

J goods

Z	industries
AG	agricultural industries
AG1	agriculture with variable use of land
AG2	agriculture with constant use of land
AG3	agriculture with constant cover index
AG4	agriculture with variable cover index and variable use of land
AG5	agriculture with variable cover index and constant use of land
IND	production industries
I1	capital utilizing industries
I2	capital producing industries
I3	non-capital producing industries
IM	imported goods
IM1	imported goods less fertilizers and pesticides
NIM	non-imported goods
EX	exporting industries
NEX	non exporting industries

D. LIST OF VARIABLES

Endogenous variables

<u>Economic model</u>

CD	Private consumption of goods
DK	Real investment of good in industries
EE	Exports from industries
EXPEND	Total nominal private expenditure on consumption
F	Use of fertilizers in agricultural industries
GR	Government nominal net revenues
JJ	Total nominal real investment expenditure
KL	Tanzanian shilling units of land
LN	Nitrogen from land measured in Tanzanian shilling units
L	Use of labour
MM	Import of goods
N	Nitrogen
P	Producer price of composite deliveries
PA	Use of pesticides in agricultural industries
PC	Composite purchaser price
PD	Producers price on home-market deliveries
PKL	Price of homogenous land in «cof» and «tob»
PRFT	Total nominal profits in the industries
SGOV	Government nominal savings
X	Units of production by industries
XC	Units of composite purchaser good
XD	Units delivered to the home-market
Y	Nominal private income

<u>Soil model</u>

D	Soil depth
NE	Lost nitrogen due to erosion
NR	Naturally mineralized nitrogen (soil mineral nitrogen)
NRR	Nitrogen from roots and residues
NS	Stock of nitrogen in Soil Organic Matter

Parameters and exogenous variables

Economic model

α	Productivity of labour in production function
β	Productivity of real capital in production function
γ	Productivity of nitrogen in production functions for agricultural industries
χ	Productivity of pesticides in production functions for agricultural industries
μ	Productivity of homogenous land in prod. functions for agricultural industries
θ	Basic consumption in LES-functions
κ	Budget share of available expenditure after spending on basic consumption
τ	Substitution el. for consumption between imports and home produced goods
ρ	Transformation el. between exports and home marked deliveries in production
Ω	Transformation coeff. for land-nitrogen to physical unit as fertilizer-nitrogen
a	Units input of goods per unit output of goods in industries
bb	Calibration coefficient in non-agricultural industries
c	Marginal propensity to consume
cs	Change in stocks
er	Currency exchange rate (Tanzanian shilling/USD)
gc	Government real consumption
h	Export share parameter in the export/home-market transformation function
hh	Shift parameter in the export/home-market transformation function
imat	Investment good's share of nominal expenditure on investment in industries
kshare	Each industry share of total nominal expenditure on investment
kl	Constant land area
lg	Governmental use of labour
pkl	Price of homogeneous land in agriculture where use of land is endogenous
pe	Unit price to the producer for export goods
pm	Unit price of imports at the border
q	Import share parameter in the import/home-market substitution function
qq	Shift parameter in the import/home-market substitution function
sfor	Nominal financial transfers abroad (USD)
ta	Subsidy rate
td	Taxation rate on goods delivered to the home market
te	Taxation rate on goods for export
tech	Technological productivity parameter
tm	Taxation rate on imported goods
ty	Income taxation rate
w	Nominal wage

Soil model

λ	Percentage direct mineralization from roots and stover (non-harvested crops)
bds	Soil density
cp	Vegetation cover function coefficient
cpa	Vegetation cover index
cpars	Vegetation cover function coefficient
crs	Nitrogen concentration in roots
exxs	Transfer parameter for crops from money to physical units
hs	Food's share of food (harvested crops) and stover (non-harvested crops)
ks	Erodability of the soil index
nas	Atmospheric nitrogen deposition

ncss	Nitrogen concentration in stover (non-harvested crops)
ncrs	Nitrogen concentration in roots
phis	Transfer parameter for nitrogen from money to physical units)
ms	Nitrogen content in eroded soil
retain	Proportion of stover (non-harvested crops) kept in soil
rns	Nitrogen mineralization from SON
rs	Climate and rainfall index
srs	Proportion food and stover (non-harvested crops) to roots
ss	Slope index
ws	Depletion of eroded soil index

E. List of Industries and Goods

	J	Z	AG	AG1	AG2	AG3	AG4	AG5	IND	I1	I2	I3	NIM	IM	IM1	EX	NEX
Cotton	X	X	X	X		X	X					X	X			X	
Coffee	X	X	X		X	X				X		X	X			X	
Tea	X	X	X	X				X		X		X	X			X	
Tobacco	X	X	X		X	X				X		X		X	X	X	
Cashew	X	X	X	X				X		X		X	X			X	
Cassava	X	X	X	X		X	X					X	X				X
Maize	X	X	X	X		X	X			X		X	X			X	
Rice	X	X	X	X		X	X					X		X	X		X
Other cereals	X	X	X	X		X	X					X					X
Beans	X	X	X	X		X	X					X	X				X
Bananas	X	X	X	X		X	X					X	X				X
Other Crops	X	X	X	X		X	X					X		X	X	X	
Livestock	X	X							X	X		X	X	X	X		X
Forestry	X	X							X	X		X		X	X	X	
Food	X	X							X	X		X		X	X	X	
Textiles	X	X							X	X		X		X	X	X	
Other Manufacture	X	X							X	X	X			X	X	X	
Construction	X	X							X	X	X			X	X		X
Electricity	X	X							X	X		X	X				X
Transport	X	X							X	X		X	X			X	
Other Private Services	X	X							X	X		X		X	X	X	
Pesticides	X													X			
Fertilizers	X													X			
Total	23	21	12	10	2	10	8	2	9	14	2	19	11	12	10	13	8