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# Mitigation of Large-Scale Biofuel Expansion with Smallholder Conflict: Modelling of Land Use Dynamics using Control Theory for Policy Design to Sustain Food Security and Improve Productivity

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*Abstract*

*With the introduction of biofuels a conflict newly remerges between cash crops, mostly for export, and food crops, mostly for food security. It is also feared that mono-cropping threatens the agro-ecology in developing countries impeding future food security. We seek coexistence minimizing negative impacts on productivity. We show how to model explicitly land distribution and transition through a dynamic approach containing large- and small-scale sectors competing for land and labour as stocks. We display short- and long-term effects on competitiveness of sectors and degradation potentials are addressed. Specifically skill and knowledge acquisition are modelled as dynamic processes beside soil fertility. Additionally transaction costs on land development are reckoned. Land transfer and food pricing are modelled as control variables and distinguished from stock variables incl. human capital and soil fertility. Yet control (policy) variables are land taxing and food subsidies. Soil fertility in smallholder farms is based on manure; biofuel uses imported fertilizer.*

Keywords: Biofuel Expansion, Dynamic Policy Modelling, Control Theory, Food Security

JEL codes: O4, Q13

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## 1 Introduction

The expansion of biofuel production is now a hotly debated issue. However, it is not the intention of this paper to go into reasoning for biofuel (chances, yes or no, politic, etc.; rather we will look at consequences and necessities to address the phenomena by innovative modelling. From an economic point of view, biofuel expansion is often considered a welfare increasing option for land use in land rich developing countries (Arndt et al. 2010), because it offers income, employment and forex chances; but many issues have also emerged. It is feared that food security is impeded, ecological problems (as related to mono-culture) emerge, and negative distributional consequences will result.

For facts and for delineation: Biofuel expansion usually means that land is acquired (bought) for production by large-scale farm operation and the farming system changes from smallholder to large-scale farming; large farms take over whole landscapes by deploying monocultures (for sugar cane, palm oil, soya bean plantations, etc.) and smallholder farming quits. Besides social concerns of corruption, land grabbing, etc. (de Schutter, 2011), there are ecological concerns. Though soil fertility shall be guaranteed by modern, fossil fuel intensive farming, techniques using mineral fertilizer, etc., this is queried (Nkonya, 2008). There is an emerging critic that a switch will destroy agro-ecological bases. It is said smallholders farm labour intensively and use manure while biofuel relies on fertilizer and this eventually does not payoff in the long run; smallholders lose their land and also food basis and landless people will be exploited. It is said that the agro-ecology is threatened because large farms rely mostly on chemical input whereas smallholders rely on ecosystem services. In particular, in this line of thought, it is feared that modern technologies will destroy the environment as well as livelihood of millions of rural people at the expense of foreign currency favouring elites.

To sketch the discourse further: On the one hand we can observe a very optimistic view, which visualizes investments as highly welcomed and necessary for rural development; and it shall bring prosperity to rural areas as models show (Arndt et al. 2010). Reaping benefits from modern technology, land conversion especially shall help the disadvantage. A promise is that rural areas will flourish as never flourished before. Yet, ecological effects are mostly neglected because they are dynamic (in future) and difficult to catch. Proponents and opponents strain different things/wishes.

In principle, by proponents it is argued that land expansion for bio-fuel is not an issue at which one should look critically. It creates jobs and improves wages for landless, poor populations as gains trickle down. By letting things go, rural growth can become dynamics which offers even higher income, employment, etc. than today, and finally expansion results in prosperity where everyone automatically benefits. On the other hand there is an emerging sceptic and critic, not only in detail but also fundamental by opponents; to sketch it in in short: smallholders will lose their food basis and landless people will be exploited (the issue of smallholder vs. large farms is up again see Piesse and Thirtle, 2009). But even more important: environmental issues on soil fertility have merged. Some experts fear that modern technologies which are coming with biofuels (here to sensible agro-ecological zones) will destroy soil fertility and livelihoods of millions of rural dwellers at the expense of foreign currency (influx for elites: see: Wiggins et al. 2010). This argument is based on a selective technology choice assumption. Then a hypothesis (on inappropriate rights on resource use) is put forward (for detail see Committee on world Food Security, 2011) saying large companies will just exploit resources leaving the countryside deprived. To complete, the discourse raises many questions about dynamics and requests new modelling on dynamics and impacts on long run welfare.

The question the paper addresses is: can we offer improved modelling? Especially by applying bio-economic modelling (and system analysis) we should take into account ecologist and some agronomists arguments about worries on negative impacts on ecosystem services; they see degradation form mono-cultures and threats for ES services requesting more chemical inputs; at least organic matter decline (Anderson-Teixeira, 2009; i.e. if not correctly addressed, wrong assessments emerge). In this regard our modelling will includes a dynamic forecast of soil productivity depending on investment in fertility and recognizing temporal costs to maintain fertility. Smallholders will offer, for instance, manure from livestock, rotation with grassland, etc.; and farming with labour which is part of their farming system. Also since smallholders offer a diverse landscape and maintain natural vegetation for ES, we must show how a policy of taxing and cross subsidization between bio-fuel and smallholder sectors can help to overcome ecological and distributional concerns in the long run.

From a perspective of modelling, socio-economic and agro-ecological dynamics of biofuel expansion eventually may matter more than static issues. We have to exemplify what happen to value added in future as compared to traditional static modelling? It can be expected that comparative static models have only a limited capability to provide sufficient insight because policy is once given and does not adjust over time. But the system is dependent on policy change. Vice versa options for contingent policy interventions are to be based on short and long run considerations; they even have to anticipate long-run effects! In fact, comparative static models are weak in controlling processes. In as much, as requests to control dynamics in favour of recognition of environment and balanced developments are emerging, it can be put into question whether assumptions of simple land markets (like in CGEs) will be appropriate in forecasting dynamics and imbedding policies based on path dependency. In many countries changes in the agricultural sectors with regards to biofuel expansion seems to be very dynamic and scales matter; but dynamics have been neglected. Africa is an interesting case (for an overview on issues see Deininger and Byerlee, 2011). Nevertheless, from an economic point of view biofuel is an option for cash crop production, diversification and export earnings. And despite critics (on the discourse see: Kuchler and Linnér, 2012) a coexistence may work.

It is the objective of this paper to address critics on biofuel through dynamic modelling; but maintain scope for benefits, address costs and spell out a steady state which can be seen as a co-existence. The coexistence shall be based on dynamic policy response, for which we use control theory. In the paper, we take the following steps: (i) we take natural productivity constraints into account in dynamic modelling, (ii) show how policies of taxing and (iii) cross subsidization between biofuel and smallholders can help to overcome concern of the rural economy; and (iv) we address the long run effects of biofuel expansion. To start after specifying the aims, for understanding, we firstly must coin the problem. Secondly, a control theory outline on the dynamics will be offered.

## 2 Aims of the Study

Since concepts rely on aims, we now further specify aims which we will pursue suggesting an explicit dynamic modelling. As the aim of this paper is to look deeper into dynamics of expansion, we suggest coining biofuels as control problem. A control problem constitutes policy related paths for specific dynamic development. If we want a steady state of co-existence between biofuel and food production, we must work out a contingency of dynamics; deal explicitly with adjustment processes. The approach shall balance gains from profits and income generation in large-scale biofuel with smallholder food security as well see implications for soil fertility management thereby looking at different technology options, income and food security for smallholders. It’s a compromise.

From an investigation technique perspective the aim is to look into an alternative (extension) to CGE modelling; i.e. to generalize and model land allocation (distribution) through simulating dynamics of sectors (large- and small-scale), here jointly, to work out options and policy.  We will introduce adjustments of underlying stock variables which display long term effects changing competitiveness of sectors. Precisely skill and knowledge acquisition are modelled explicitly as government sponsored dynamic processes depending on taxation of biofuel sectors as well as the aspects of soil fertility is taken, i.e. artificial fertilizer vs. manure are integrated. In this regard the model is not a pure casual model; rather controlled processes prevail. At government level, transaction costs on land registering are taken into account and land transfer is explicit. Sectors compete for land and labour at marginal returns due to dynamics and a threat of degradation (mono-cultures) is introduced.

As an explicit aim concerns of agronomists about negative should be to also into account, and impacts of bio-fuels on soil fertility and biodiversity are expressed in degradation threats. Eventually, even issues on natural capital become involved. Incidentally our modelling includes a dynamic equation of soil fertility which cares for degradation, i.e. investments in fertility maintain and costs.

From a technical point of view dynamic control theory serves to optimize policy interventions and instruments by using a social welfare function. The control task includes: (1) income generated by biofuel, (2) income (value added as food equivalents) in smallholder agriculture, and (3) utility or willingness to pay for food (cheap food and real income) of landless labourers. A discounted welfare function is balancing future cost and benefits. Hereby we work with social welfare (Just et al. 2002). The general idea is that biofuel generates income for landless, i.e. "must" contribute to food security; but prices also increase. Food prices may rise as indirect impact of lower food production assuming that food is not perfectly tradable. Overall food security improvements are only possible if incomes are converted into purchasing power (real prices). We use a virtual land approach for food availability at reasonable rates. (For arguments: look at existing village models; though they are static CGEs by Taylor et al. 1999) But we go beyond static CGEs (see Diao and Thurlow, 2012, asking for recursive models) and we argue that policy instruments need to be dynamically planned.

The focus (aim) is to constitute coexistence as a steady state (modelling) between two sectors and we shall explore strategies of integrating biofuels in concepts of maintaining soil fertility, balance land use and improve productivity. Soil mining as frequently raised concern will be mitigated for a sustainable future of biofuel. This is addressed by a co-financing of fertilizing soils through biofuel.

## 3 Coining the Problem

In standard economic theory markets may lead land use change (decisions) and sector allocation; land may be considered like any other commodity and transactions should be linked to willingness to pay for land and land moves to best customer. This assertion depends on productivity differences (see below concerning welfare economic implications and normative aspects). Food producing smallholders may get only land if they are competitive; however it might be a dynamic process and, though productivity in food production of smallholders is low today due to (i) degradation, (ii) poverty and (iii) mediocre land management (Nkonya et al. 2008), it can increase. A question is how can smallholders realize better returns, retain land and produce more food, locally? In contrast, if biofuel expands, food is obtained (imported) without land; will it be at low costs? Will food be produced by skilled farmers somewhere else (in the northern; Arndt et al., 2010)? Is imported food really an alternative for more than 20 years ahead? These are big questions and reality might change if state can invest in skills of smallholders. If smallholders become more competitive on land markets, because competitiveness depends on productivity of labour, biofuel might show less fortune. As any infant industry argument, behind the scene, these deliberations require a dynamic analysis.

To acknowledge research does not start from zero, the issue of expansion of biofuel production and land acquisition for bio-fuel production has been already addressed by several authors. For instance, to understand interactions between food and biofuel analytically, here by modelling interactions and offer analytics, Dyer and Taylor (2011) and Hertel et al. (2011) investigated income links. But such approaches are mostly conducted in modes of comparative static analyses. At levels of general policy issues (such as food security, food prices and market interactions, Chakravorty, 2011) and with regards to poverty (land access: Arndt et al. 2010) we see a debate on trade-offs or synergies. Specifically employment creation in the biofuels has been put forward as a positive issue (even gender aspects emerged, see Arndt et al. 2011). But assumptions still matter: where does the labour come from? In particular the question is: will the rural poor benefit from being employed at large farm producing biofuel crops for international market or suffer food shortages; no longer working in their fields is a danger? Structurally demand increases. So we have to address a labour market incl. self-employment for food. Also, especially in modelling (for impact analyses), questions of comparative static vs. dynamics are relevant. The labour absorption has a stock and flow aspect. Change is flow, because (i) path dependency exists and (ii) private and public investments in technology change are dependent on expectations. (iii) Such aspects are difficult to model in comparative statics. Surely, taking land and labour markets as driving forces behind, we need to investigate stock and flow effects separately and combined; i.e. (iv) policy instruments change comparative advantages. But changing comparative advantages is mostly not addressed, so far, in CGEs. But active anticipation of future productivity changes might change today’s behaviour (see Diao and Thurlow, 2012).

To the knowledge of the authors, CGE models (though (i) very detailed, (ii) being capable to address decompositions such as social stratifications, (iii) work with different technologies in different sectors etc.) have difficulties with dynamics and recursive effects as well as policy design as response to change. Here we ask how to address the (iv) issue of low land value in smallholders (due to poverty as dependent on low productivity)? We see (v) few cash income (Arndt et al, 2011, Taylor et al. 1999, Dyer et al. 2011) and poor farmers cannot buy land. A strategic question is: can re-distribution and public investments interact? Also assumptions like: (1) equating wages of skilled and un-skilled labour between sectors and (2) needs to differentiate technologies (simple vs. high) for production of foods vs. biofuels are crucial. Such topics are only marginally addressed in CGEs.

To summarize: (1) the discussion on interactions (biofuel, food, productivity, and soil fertility) must be linked to dynamics in real case (local food prices). (2) Looking at policy implication (control and mitigation) this requires an explicit recognition and fine-tuning of pathways (as partly done in Diao and Thurlow, 2012). (3) Especially, environmental aspects (soil degradation and productivity) need to be put better into dynamics (they are only partly addressed: Steinbuks and Hertel, 2012; so far).

## 4 Modelling of Dynamics

We suggest a new modelling concept based on pathway dependency with policy instrument aiming at inclusion of inter-temporal fertility management, food security and skills improvement. Therefore we present a dynamic approach of adjustments (stocks and flows) which is built on control theory. In the model land fertility, productivity change and land transfer are indirectly controlled by instrument variables. The approach explicitly models annual redistribution of land (as transfer creating costs and this is recognized). Land is a stock variable and transfer of land is a control variable.

We start clarifying on modules, first; in principle we see three parties (modules) involved in land reallocation in case of biofuels: (1) small-scale farmers are providers of lands, currently in subsistence with underdeveloped potentials, (2) large-scale biofuel operators are recipients of land looking at investing in mechanised operation and creating employment which is recruited from a regional labour market, and (3) local labourers (consumers of food) who are released from the smallholder sector or are part of an underused labour force. We address 2 production and 1consumption sector which are linked. Further, in both production sectors, we are facing the need to model re-investment in productivity. Policy can increase skills which change productivity by extension.

Second we will soon develop interest functions for parties (private) and a government which pursue social welfare (public). The government is recognized as taking interests for society which is composed to the sectors' welfare; we state economic objective functions incl. food security for sectors. The model can be considered a dynamic game and control theory serves as solving tool. The needed variables are specified below. Also dynamics are addressed by new stock variables, for example by knowledge acquisition; here for smallholders, showing dynamic increases in efficiency if trained. The results changes comparative advantages of large-scale farming vs. smallholders.

For further discussion: stock variable (upper case letters later) and flow variable (lower letters) are:

- "S": skills as learning and acquiring better knowledge in small-scale farming due to expenditure for extension services as instrument variable "$e_s$";

- "C": comparative advantages as an element of cost function of large scale farms changeable through fertilizer use $w_f$ and subsidy $z_f$,
- "$L_b$" land (l is redistribution) which is in large-scale (biofuel) sector and land in the small-scale "$L_s$" sector total land. $L_t$ is total land.

Additionally we have the constraint:

- total land: $L_t = L_b + L_s$ (to be expanded) and
- to specify a financial constraint on tax revenue equals public expenditures (explained below).

Purchasing and selling land equates at shadow prices. Smallholder human capital (skill formation) is subsidised and purchases of land by large biofuel farms can outcompeting smallholders subsides; if land is not transferred land prices become too high. Extension expenditure (for skills) and transaction (registration costs) require money and taxes are raised as revenues to meet expenditures.

## 5 Innovative Concept

Our dynamic approach to biofuel expansion (as innovation in gradual change modelling) introduces land demand equivalents based on food needs. Land demand equivalents have to be met for food security. As in the obvious binary case (biofuel and subsistence, only) land is redistributed between land released and received. We add further food demand to be met by import and put that in a "total" demand. Indeed we have to add the expansion of landless as class or here stock for defining modelling categories as variables. This changes the land constraint to a potential constraint which reflects land in terms of total food equivalents; food is translated into demand for land. Admittedly, in a market type of analysis "price" is the coordination mechanism of food demand and supply, not land; but change in land deficits or abundance result in over-demand or deficits "D" (see equation 1). Populations in subsistence and biofuel matter. A deficit is accompanied by a price rise (see later) and deficits are created by newly established demands for biofuel in terms of new land. Thus a decline of land in smallholder sectors (surplus) and new land equivalents of food deficit coincidence.

$$L_b - L_s^r - L_s^v + L_d^r = D \qquad (1)$$

where: L: land with suffixes s: smallholder, b: bio-fuel
D: Deficit
d: demand of food of landless rural population employed in bio-fuel
v: virtual
r: real

A virtual land demand and supply as difference (land which is equivalent to food needs) appears. (If not meet by imports "demand" is putting pressure as land requests for food). Smallholder land or land which can be provided by surplus (vs. subsistence) is needed to feed deficit populations: $L_s^v = L_n^v$. Rural population which is not involved in small-scale production for the market is considered virtual user and the deficit and higher prices are a negative result of the biofuel land expansion.

Apparently changes in food prices (scarcity) depend on demand (increase) and supply (reduction), but also on imports; land and labour regimes are supporting food demand of the poor. One way is treating large farms as limited income generation units (see below) and looking at decrease of local land for food, simultaneously. Hereby, complexity is dealt with by treating extra-demand as a matter of land. Instead productivity increases in food production can compensate land loss. However, at a first look and actually, annual redistribution speed is at the core. Extra-demand towards small-scale local food producers will be a problem if it is not met on time (land scarcity) by productivity increase and prices will rise. Moderating it we introduce a subsidy financed by biofuel. With a subsidy the reference demand is changing because costs (or felt costs) being disadvantageous can be reduced by giving subsidies for food. But still prices can change for stimulation of productivity increase. For government pursuing social welfare this is important to improve security.

## 6 Stating the System Dynamics and Use of Differential Equation

To minimize on complexity, but still reckon system dynamics, we recommend three dynamic constraints (plus static constraints) which, in case of land use transformation, depict changes in land availability, productivity for biofuel and small-scale and agro-ecology; i.e. variables dependent on state (stocks) and control (flow) variables. We begin with human capital/skill and then expand to comparative-advantage because this helps to establish state and control variables for food security improvements and then we outline the corresponding depiction of land transfers in that system.

### *6.1 Skills/Social Capital*

Our hypothesis is that skills / human capital determine productivity and that smallholders could become more competitive if promoted. The term skills “S”, as human component of productivity of smallholders, and “C” comparative advantage as natural component of fertility (see below), are reckoned as relative terms. For skill measurement we can integrate capacities to apply improved technologies. Skills refer to agronomic knowledge in the two sectors differently and address the interaction between costs and benefits relevant for land competition; importantly one can invest in knowledge. In biofuel production we have unskilled labour. We are looking at skill improvements in smallholder agriculture -and will show how skill improvements modify the demand function of land for sectors at the level equating land markets. (The function for comparative advantages runs the opposite, below.) We assume soil fertility of the biofuel sector is relatively declining with increase in skills of the small-scale scale. And an increase of the biofuel occupation of land reduces local farming knowledge. Instead the comparative advantages can increase with fertility management which is primarily those of buying fertilizer (below). For skills we have:

$$\dot{S}_s(t) = (1-\nu_{c,s})S(t) - \nu_{s,s}[1-L_b(t)] + \zeta_{s,s}e_s(t) + \zeta_{s,f}\, f_s\ (t) \qquad (2)$$

where additionally:
S: skills
$e_s$: education
f: fertiliser

Skills can be measured as index close to total factor productivity. Though factor productivity is an outcome, it has been shown to give a good idea of competiveness and it is frequently used as proxy (Lusigi and Thirtle, 1997). We consider skills as relative: $S_s(t) = S(t)[1- S_b(t)/S(t)]$; i.e. skills determine competiveness on land markets and, if not supported in biofuel ("natural" decline in biofuel) with respect to food production smallholders in future will be more competitive than today. But skills decline with a certain rate. The equation (2) might be achieved by regression analysis and is location specific. A link between market involvement and productivity exists (fertilizer use: Govereh and Jayne, 2005) augmenting extension. The argument for skills as dependent on expansion of a large scale sector is that this sector attracts better land/ workers from small-scale who move and productivity in the sector declines; it cannot fully develop.

### *6.2 Fertility and Comparative advantages:*

#### 6.2.1 Used Framework

In a second dynamic constraint we particularly address the issue of declining natural fertility of soils, primarily in biofuel, which is suggested by many researchers (Lal, 2006). Again it is relative (Frohberg and Hartmann, 1997); but now for biofuel $C_b(t) = C(t)[1-C_s(t)/C(t)]$: this norming will allows us to work with on variables for relative. Decline happens, if no investments in fertility are undertaken. As technology applied in the biofuel sector is industrial agriculture, fertilizer is the mean to combat declining fertility. The issue is whether fertilizer is an instrument variable: yes or no.

$$\dot{C}(t) = (1-\nu_c)C(t) + \nu_s S(t) + \nu_b L_b(t) + \zeta_c\ f_c\ (t) \qquad (3)$$

where additionally:
C: competitiveness based on comparative advantages

f: fertilizer use in biofuel

Why fertilizer? Notice, the aim of modelling is usually not to specify *any* likely variable; rather a reason for defining an instrument variable is normally to get useful policy insight and to reckon the effect of key variables in a system-wide approach. In that regard, our variable C(t) expresses competitiveness as relative productivity and looks for interaction with fertilizer. Private costs and benefits are contingent on it (below); our system relies on decision making of governments which seek to influence productivity. In this respect government cannot influence comparative advantages directly through land use; but subsidizing fertilizer helps to maintain productivity. In governing one can, for instance, venture into even more indirect modes looking at tax discounts for fertilizer. Normally imports of fertilizer are strongly taxed to get government revenues. A tax discount would reduce finance (aspect of financial flows, discussed below), so we need refinancing to avoid that, etc.

The aspect of changing comparative advantages of large-scale biofuel vs. smallholders has implications for land markets. Bio-fuel companies must discount future positions for prices at land markets facing declining fertility; so "we" (system analysts) have to tell them pathways. Then taxing land is normally considered a sin from the point of view of commercial operators. But working with comparative advantage for large-scale exploitation, the threat of comparative disadvantage can change acceptance (Piesse and Thirtle, 2009). The argument is: decreasing land returns for large-scale, modern farming (in future) will discourage purchases and hence decrease the growth of factor productivity, here as process (Rada, 2012). A negative sign can be expected for productivity change by equating total factor productivity with taxing of land; primarily because taxing implies a lower adoption of large, seemingly, inefficient farming (knowing comparative advantages depend on fertilizer). Then, knowing fertilizer demand function equation (see below), one can expand:

$$\dot{C}(t) = (1-\nu_{c,c}^{0})C(t) + \nu_{s,c}S(t) + \nu_{b,c}L_{b}(t) + \zeta_{c,c}[\theta_{f,0}^{d} + \theta_{f,1}^{d}p_{f}[1+t \cdot z_{f}(t)]] + (1-\nu_{c}^{1})p_{l}^{0} f_{b}$$

where additionally: (3')

$z_f$: subsidy on fertilizer

$f_b$: fee (tax) on land

where $z_f$ is a discount (tax exemption) on fertilizer (tax t) explained below in detail. The description of fertilizer demand works with a ceteris paribus assumption stating a partial equilibrium (marginal product) of fertilizer and assuming world price constant.

Importantly in the comparative advantage/competitiveness equation (3) we can easily include the ecological concerns about biofuel and mono-cropping. As we can specify the metric in terms of natural fertility, which is residual land productivity, the coefficient ($1-\nu_c$) gives the degradation danger. It serves in simulations as trigger of the system. Economically the need to go for artificial fertilizer will specify increased costs; eventually it is too expensive to maintain fertility in biofuel. Interestingly we can further include interactions of sectors. Since different landscapes (mix of less intensive smallholder and biofuel) show different fertility coefficients $\nu_b$ $L_b$ as $\nu_b(1-L_s)$ can be differently qualified. Hereby it is assumed that smallholder agriculture is less dangerous for degradation.

### *6.2.2 Proposal for Expansion of Ecological Concerns and Productivity Change*

Ecological aspects can be more explored (Lal, 2006). To deepen the analysis measures, such as productivity (yields) as measure for C may take account of ecological indicators; in (3’’) we combine using organic matters O. Then dynamics for total factor productivity incl. organics are at this direct:

$$\dot{C}(t) = (1-\nu_c)C(t) + \nu_s S(t) + \nu_b L_b(t) + \nu_g O(t) + \zeta_c \, f_c \, (t) \tag{3''}$$

where additionally:
$O_g$: organic matter in fallow land

For an analysis (3’’) states: organic matter increases factor productivity and incl. organics delivers a fourth dynamic; it is an account of fallow land use and animal rearing with smallholder conjunction.

$$\dot{O}(t) = (1-\nu_o)O(t) + \nu_f F_s \, (t) + \nu_a a_g(t) \tag{3'''}$$

where additionally:
$F_g$: fallow grassland
$a_g$: animals providing manure

Apparently venturing in dynamic and joint-ness aspects (3’’’) of detailed long-run effects of composition of land use, fallow, organic matter, soil fertility, etc. (see Cong, 2014) the composition of farm and land use types must be included. For instance hypothesising that animals and manure application, hitherto animal rearing and grassland, play a major role in certain agro-ecological and farming systems, equation (3’’’) can exemplify links to and cost and benefits of organic matter O(t), fallow F(t) and animals rearing a(t). This shall enter the objective function of smallholder farming. A technical mode is to take the second derivative of comparative advantages depending on changes:

$$\ddot{C}(t) = (1-\nu_c)\dot{C}(t) + \nu_s \dot{S}(t) + \nu_b \dot{L}_b(t) + \nu_g \dot{O}(t) \tag{3‘‘‘‘}$$

and insert the function of organic matter (3''') in (3'''') . This reduces the number of differential equation, but request to work with change of change. For the moment, for demonstration, we skip these aspects and think ecological aspects are taken care of in (3'); i.e. they are partly covered.

## *6.3 Land*

### 6.3.1 Flows

We have to specify stocks and flows at land market level. For simplification of land transfer (flows) we assume that land transfer is under restriction and we distinguish uncontrolled and uncontrolled transfer with government restriction. Our formulation starts with a definition of land change:

$$u_b = \xi \; u_{b,s} + [1-\xi] u_{b,f} \tag{4}$$

where additionally:

u: land transfer: $u_b$ market (+) and $u_s$ government (-)

The interpretation of this equation is as follows: land transfer to the biofuel sector either occurs with a probability ξ which is associated with a relief from deficits for rural populations and this is expressed as land equivalents; or counter-probability [1-ξ]. Probabilities can be made event. dependent on food price increase (linear response function). Or they are considered exogenous. Here, the coefficients are cite-specific. In principle they reflect knowledge extern to the system investigated.

### 6.3.2 Stocks of land and dynamics

For land reallocation (redistribution between biofuel and smallholders) we assume that food deficits cannot be perfectly met by external sources (local supply or imports from world market); rather deficits increase prices. (The outside supply is not fully elastic.) And as price and productivity increase are halfway in food deficit compensation, security is endangered. Even, in usual abstract CGE modelling, price would increases accompanying deficits; but labouring in large-scale does not meet income needs. I.e. pertinent from a low level of income, price increases are also relevant as dynamic issue. We doubt that with higher prices more food can be obtained from markets; since most people are poor, price increase needs to be addressed in a more straight way. It is an empirical problem to establish a correlation of price, deficit and land (Dyer and Taylor, 2011). Food deficit is a land issue; actually a country imports land equivalents and the size of deficit impacts on biofuel options. Reducing a deficit can release more land for biofuel (normatively). We start by using virtual land:

$$L_b = L_s^t - L_s - L_d^v \tag{5}$$

where: $L^t$ = total land plus
$L^v$ = total land

Imported “land” either comes from another province or abroad. The constraint can be also read as: land in biofuel either comes from smallholders or it contributes to deficits. A deficit can be expressed as virtual land for smallholders who are in deficit of food and have to work for income, spent on food. Land and food are correlated by yield per ha. As reference, if there is no biofuel income, smallholders must fill deficits of rural dwellers. Equation (5) implies that a certain number of farmers produce not enough food. Income generation is important, yes; but deficit folks look for buying food at local markets, and regional food price prevails as well as smallholders need land. Then the expected food price level shall be a function of virtual land deficits, i.e. there is correlation between a need to have land and accepted food prices. Again, the assumption is: external food from trade is limited and only price increases will guarantee more inflow. This depicts a typical rural setting of African country food procurements (Govereh and Jayne, 2006) relying on local markets.

Such constellation means some deficits can be accommodated by food from the world market; but not all. However we postulate, land demand and transfer is due to some flexibility (local price spread above initial price). I.e. the actual food price will rise above a reference price. The reference price is normally the past price, or it can be modelled in the course of dynamic development as a scenario where biofuel would not appear. A reference demand is specified as (6) and the change is:

$$L_d = \alpha_{f,o} - \alpha_{f,1} p_f \text{ and for change: } \dot{L}_d = -\alpha_{f,1}[p_f - p_f^r] \tag{6}$$

Now, our land constraint (5) and first derivative (change, equation 7) of land can be stated as an inclusion of the policy instrument of retaining land in the smallholder sector (virtual land is covered):

$$\dot{L}_b = -\dot{L}_s - \dot{L}_{s,d} + \alpha_1 [p_f - p^r]_1 - u_s + u_b \tag{7}$$

and for the use of the policy instrument of subsidizing food.

$$\dot{L}_b = -\dot{L}_s - \mu\ \dot{L}_{s,d} + \alpha_1 [p_f [1 - z_f] - p^r] + u_b \tag{8}$$

Actually inserting in land redistribution (4: as change variable of land use) it gives us in general:

$$\dot{L}_b = \xi[\dot{L}_{b,s} - [1+\mu]\dot{L}_{s,s} - \alpha_1 [p_f - p^r] - u_s] + [1-\xi][\dot{L}_{b,b} - \dot{L}_{s,b} - \alpha_1 [p_f [1 - z_d] - p^r] \tag{9}$$

For clarification equation (9) is a dynamic constraint which includes the land use change and food needs: i.e. if $\xi$=1 (from flow specification in equation 4) holds, the physical transfer matters and the government controls the transfer of land use in the biofuel sector, i.e. by determining $u_s$. (here controlling transfer of land, see below). If $\xi$=0 holds, the food sector (i.e. of the deficit by landless population) response is the instrument of choice limiting change; it restrains transfer. The coefficients reflect socio-political situations of countries and need to be derived from investigations. Concerning the role of adjusting, food situations of landless matter (cases need to be distinguished by government types of intervention). The second case documents willingness to go for (market) prices as type of control. In contrast, in first case, quantity controls prevail. Above, we have to split analyses between transfer demand of the biofuel and retention of smallholders. Inserting in (5) we get:

$$\dot{L}_b = \xi[\dot{L}_{b,s} - [1+\mu]\dot{L}_{s,s} - \alpha_1[p_f - p^r] - u_s] + [1-\xi][\dot{L}_{b,b} - \dot{L}_{s,b} - \alpha_1[p_f[1-z_d] - p^r] \tag{10}$$

Then two terms are introduced. First, we state that there is a linear correlation between changes:

$$\dot{L}_{b,s} - \dot{L}_{s,s} = \kappa_1[\dot{L}_{b,b} - \dot{L}_{s,b}] + \mu\ \dot{L}_{s,s} \tag{11}$$

The coefficient $\kappa_1$ can be retrieved from CGE modelling. It states the supply of additional biofuel land (from smallholder) dependent on release of land and change vice versa. Equation (11) makes equation (10) a function dependent on expected change and change possibility, respectively. For the moment this substitutes private planning. Changes occur in case of the price compensation for land. A brief remark on the empirical background finding coefficients: they can be found from running CGE models varying policy instruments (for example in recursive CGEs: Diao and Thurlow, 2012).

Then acquisition of biofuel depends on differences in policy regimes which are found in equation:

$$\dot{L}_b = \xi[\kappa_1[\dot{L}_{b,b} - \dot{L}_{s,b}] - \alpha_1[p_f - p^r] - u_s] + [1-\xi][\dot{L}_{b,b} - \dot{L}_{s,b} - \alpha_1[p_f[1-z_d] - p^r] + \xi\mu\dot{L}_{s,s} \tag{10'}$$

To complete, secondly, a dependency of the change potential is regressed by $\kappa_2$ on the already obtained size of the biofuel sector and a stated link is measured in equation (12a). Coefficient can $\kappa_2$ be also derived from system modelling (again CGE) regressing policy instrument variations.

$$[\dot{L}_{b,b} - \dot{L}_{s,b}] = \kappa_2 L_b \tag{12a}$$

Finally we postulate that any empirical analysis provides a correlation $\kappa_2$ between the size of change in a case of quantity intervention and achieved bio-fuel expansion:

$$\dot{L}_{s,s} = \kappa_3 L_b \tag{12b}$$

Then finally we receive a function relationship for the dynamics such as:

$$\dot{L}_b = [\xi\kappa_1 + [1-\xi]]\kappa_2 + \kappa_3\xi\mu]L_b - \xi\alpha_1[p_f - p^r] - u_s] + [1-\xi]\alpha_1[p_f[1-z_d] - p^r] \tag{13}$$

This differential equation illustrates how a determination of the land use in the bio-fuel sector can be made dependent on a state variable and control variables. It contains detailed sector responses. Additionally, we can (must) use simulations of CGE models (or regressions) to get the coefficients grounding the analysis in static investigations of the sector interactions of smallholders and biofuel.

## 7 Linkages of Annual Constraints to policy dynamics

### *7.1 Statement on Control Variables*

The interaction of sectors: (1) biofuel, (2) smallholder production and (3) food consumption is depicted as a dynamic system which can be controlled by a government which faces additional flow constraints.  Having achieved a stock and flow variable outline for the to-be-controlled system and a concise variable specification as set of differential equation, now, we have to further distinguish uncontrolled stock and flow from controlled variables. For instance, controlled shall be: fertilizer (subsidy) $z_f$, land transfer (modified willing to transfer land $u_s$), and extension $e_S$ (knowledge transfer). Also we have a partial compensation for the potential price spread (subsidy on food): $z_d$. This would imply 4 control and 3 state variables. The rest are uncontrolled, though endogenously determined variables. We investigate this aspect looking of endogenous flows as financial constraint using Diagram 1.

In Diagram 1 marginal productivity functions of small-scale agriculture and large scale biofuel determine the temporal equilibrium on land market. The expansion of biofuel is documented by a shift of its land demand, which is moderated by a tax on land. The small-scale sector receives a subsidy for land which is not transferred. Auxiliary marginal productivity of the smallholder sector is improved by knowledge transfer (skills). A matter of discussion (or clarification) is the mode of land transfer. As can be seen from the Diagram 1, land transfer can be influenced by subsidy. The subsidy is financed from winners, biofuel sector (though lowering marginal propensity to buy land). We resume that biofuel farms are capable to acquire land, i.e. smallholders sell (willing seller); though we aim that smallholders retain more land than in a situation of land market without subsidy.

For understanding of regulations: a retention of land can be subsidized on basis of asking farmers to show offered land prices from biofuel companies and smallholders and government officers jointly declare how much compensation is needed if land is not sold. This concept requires knowledge on offers and acceptances (marginal productivity) from both sectors (marginal optimums) and control.

### *7.2 Finance*

Coming to financial aspects, note, it cannot be an objective of government to make revenues. Rather a social welfare function has to be established, though on private costs and benefits (discussed later). Social welfare (Just et al, 2002) goes beyond financial aspects. Nevertheless the finance issue matters as constraint. The concept presented here is one of taxing biofuel and subsidizing food and smallholders for retaining welfare positions. However smallholder land, as a whole, is not part of any subsidization; rather we focus on land transactions. In equation (16) the finance is balanced as:

$$L_b f_b = [r_b - r_s] z_f^o u_s + c_s u_{b,} + c_s e_s + [p_d - p_d^o] z_d \varsigma L_d + w_f p_f [1 + t \cdot z_f] \qquad (16)$$

where additionally:
$z_d$: food subsidy
$c_s$: transaction costs

In equation (16) policy variables (in terms of expenditures) are: (1a) the wished retention of land to be transferred, (1b) the rate of subsidy needed for smallholders not to transfer land, (2) the finance for extension (annual payment) and (3) the rate of food price increase mitigation. (4) A further policy variable for biofuel farms (in terms of procurement) is the land tax (giving the revenues). But farms also receive a subsidy on fertilizer (5); for instance a discount on import tax as simplification. Another simplification is a proportional factor stated between land in bio-fuel and fertilizer:

$$w_{f,b} = \omega_b^f l_b \qquad (17)$$

However, land transferred is residual to the finance available for subsiding retention. From this simplification, and as knowledge of the fertilizer and food demand functions prevails, a new calculation of the subsidization rates appears which expresses rates in land occupied by the biofuel sector (not shown, but evident). Hence the basis for taxing matters. Since it is assumed that the two sides, revenues (from tax) and expenditure (subsidies) are balanced, equation (16) can be used as constraint. Further we us a Taylor approximations. Based on the land demand functions the needed subsidy on land retention is a function of the desired retention. Then equation (16) is linear:

$$\theta_{1b} f_b = \theta_{2b} u_s + \theta_{3b} e_s + \theta_{4b} z_d + \theta_{5b} z_f^o \tag{16'}$$

For the technique current stocks are used. Equation (16') is working along quadratic expressions of quantities (stocks or given flows) multiplied by price (instruments) and taking references to average values which document initial or start values. (The approximation can be iterated). All five variables are subject to the same dynamic system being instrumental, which applies to: $f_p$ .$u_s$, $e_s$, $z_f$, and $z_d$.

Notice, the description of the system is a closed system of finance and physical options, and it is complemented with a subsidy for a poor population depending on food from smallholder farming having no land. Within the given concept (as can be shown) the subsidization rate for food demanded from wages in the large scale sector is endogenous taking the above financial constraints:

$$z_d = \theta_{12b}^* u_s + \theta_{13b}^* e_s + \theta_{15b}^* f_b^o \tag{17a}$$

and the subsidy for fertilizer in the bio-fuel sector is:

$$z_f = \theta_{22b}^* u_s + \theta_{23b}^* e_s + \theta_{25b}^* f_b^o \tag{17b}$$

Equation (17b) tells us that food subsidies are endogenous to finance constraints. All in all, from the point of view of designing a feasible control problem variable $z_{f,}$, though a control variable, need not to be controlled directly. For calculation it is linked to other control (flow) variables. Later, in the frame of defining objective function its optimization is implicit and $z_f$ changes contingently.

## 8 System Dynamics

Summarizing the three differential equations, the financial constraint and options for control we can depict system-wise options of land use change as controlled by a government in a matrix such as:

$$\begin{bmatrix} \dot{L}_b(t) \\ \dot{S}\ (t) \\ \dot{C}\ (t) \end{bmatrix} = \begin{bmatrix} [\xi\kappa_1 + [1-\xi]]\kappa_2 & 0 & 0 \\ (1-\nu_s) & -\nu_s & 0 \\ \nu_{L,c} & \nu_s, c & (1-\nu_{c,c}^0) \end{bmatrix} \begin{bmatrix} L_b(t) \\ S\ (t) \\ C\ (t) \end{bmatrix} + \begin{bmatrix} -[\xi-1]^{-1}\xi & 1 & \\ 0 & 0 & \zeta_{s,s} + \theta_{23b}^*\zeta_{s,f} \\ \zeta_c(1-\nu_c^1)p_l^0 + [\zeta_c\theta_{f,1}^d p_f \theta_{25b}^*] & \zeta_c\theta_{f,1}^d p_f \theta_{22b}^* & \zeta_c\theta_{f,1}^d p_f \theta_{23b}^* \end{bmatrix}$$

$$\begin{bmatrix} f_b(t) \\ u_s(t) \\ e_s(t \end{bmatrix} + \begin{bmatrix} [\xi-\rho_c]^{-1}[\xi[L_d^{v,t} - L_t^* +]\alpha_{r,1}[p-p_r]] \\ \nu_s \\ \zeta_c\theta_{f,0}^d \end{bmatrix} \tag{18}$$

In equation (18) coefficients are firstly given by combinations from combinations of the structural equations (1 to 17), which describe the system as outlined before. We condensed especially the flow equations by inserting them into the stock equations. Secondly the primary coefficients can be retrieved from and underlying CGE where some variables are exogenous and simulations of numerical results or coefficients are derived from the structural outline of the case (land shares as currently given). Re-arranging (mathematical technique of system expression) offers the general presentation (18'), and dynamics are capture as differential equation in matrix notation of stock Y and control u:

$$\dot{Y}(t) = M_1 Y(t) + M_2 u(t) + m_0(t) \tag{18'}$$

As a note on the food price: in the instrument vector u of equation (18) food price issues are part of a subsidy which is dynamically optimized. Though not explicit food security is included as option to subsidize food for the poor based on a budget on land taxing (above; also part of u); food is indirectly addressed by constraints such as equation (16). Distribution and demand functions connect food deficit issues to food pricing implicitly. The equation (18') stands for a dynamic system approach which includes several constraints at an annual basis for financing support of those rural dwellers which might be negatively affected by bio-fuel expansion. To optimize we need objectives.

## 9 Objective functions

### *9.1 Derivation of Objective Functions, Choice of Welfare Economic Concept, and Control Theory*

In control theory, the derivation of corresponding policies depends on system optimization and modelling of the policy dynamics is driven by objective functions, constraints and optimization technique (Tu, 1991). Setting up the objective functions of the three participating sectors, we focus on instrument variables such as subsidies and fees; the option to subsidize food is recognized in the constraints (financial). In particular landless poor could be simply identified as consumers; but they are not; in our approach which is going beyond partial equilibria we link them to land. They actually release land which supported subsistence. In rural areas, they become labourers and derive income from combing labour with land in commercial biofuel farms. It means real income and food security are constraints which gear the system. Hereby job and land, both, constrain income. With respect to food, for vulnerable, in this regard, the interesting topic is: combination of price/income.

We commence with the biofuel sector stating its objective as profits minus paying wages and taxes. Profits are returns related to land: land rents. From a land demand perspective our modelling is similar to those of Paris and Howitt (2001) on gross margins. As was shown by these authors applying a linear programming modelling approach and taking Maximum Entropy (ME), a quadratic expression of welfare is given. This function includes constrained land demand. An important aspect of such objective functions is that the mathematical integration (objective as areas below demand in Diagram 1) and derivation (demand) correspond to the finding of the objective function (Just et al. 2002). For instance, profits are constrained by land (market), labour (availability), capital (investment), fertility (soil), etc. Then constraints are comparable to state variables. Mathematically constrained behavioural equations serve as reference for welfare. These behavioural functions evenly correspond to those of CGE models having capacity constraints (Hertel, 1997).

Diagram 2 shows the general idea to retrieve partial objective functions from a land market analysis. Further we can work with subsidies for controlling land transfer. Note, the approach is similar to welfare economic analysis given by Just et al (2002), using the integrals under (linear) factor demand as surplus and outfitting policy instruments. Shaded areas are fees (amount) on land (horizontal) and the subsidies (vertical). The triangles are social welfare losses; while markets prevail.

### *9.2 Biofuel Sector*

Then, for the biofuel sector a constrained quadratic profit function can be stated such as:

$$\begin{aligned}\Pi_b = {} & \theta_{b,L.o}L_b + \theta_{b,C.o}C_b + \theta_{b,f.o}p_b[1-f_b] + \theta_{b,z.o}r_f z_f + .5\theta_{b,p,1}p_b[1-f_b]^2 + .5\theta_{b,L,1}L_b^2 \\ & + .5\theta_{b,C,1}C_b^2 + \theta_{b,f,1}r_f z_f^2 + \theta_{b,f,L,2}p_b[1-f_b]L_b + \theta_{b,f,C,2}p_b[1-f_b]C_b + \theta_{b,f,z,2}p_b[1-f_b]r_f z_f \\ & + \theta_{b,L,C,2}L_b C_b + \theta_{b,L,z,2}L_b r_f z_f +_{b,C,z,2} C_b r_f z_f \end{aligned} \tag{19}$$

Note. it is a function dependent on instrument variables [u] and stock variables [y] as vectors. In equation (19), in short-run, the biofuel sector shall depend on controls such as fees (land tax) and fertilizer subsidies (discounts from world market price). Matching product supply and land demand, functions for supporting the objective function are from static optimization (Howitt and Paris, 2001):

$$q_b^s = \theta_{b,f.o} + \theta_{b,p,1}p_b[1-f_b] + \theta_{b,f,L,2}L_b + \theta_{b,f,C,2}C_b + \theta_{b,f,z,2}r_f z_f = 0 \tag{19a}$$

$$\lambda_b = \theta_{b,L.o} + \theta_{b,L,1}L_b + \theta_{b,f,L,2}p_b[1-f_b] + \theta_{b,L,C,2}C_b + \theta_{b,L,z,2}r_f z_f = 0 \tag{19b}$$

Hereby we assume that “price” $p_b$ is actually a gross margin per hectare, i.e. minus land tax, and the supply is a supply, which is optimized according to gross margin calculation of farmers and $\lambda_b$ is a shadow price equating with the shadow price of smallholders (Diagram 1). Formally it means no grabbing occurs; no institution analysis. The approach enables us practical work in empirical research on specifying behaviour as response to charging a fee (land tax). All corresponding coefficients are either retrievable from supply analysis, using constrained optimization and/or programming (also they are alike to CGE-modelling). The difference in sector analysis is to control biofuel which is taxed endogenously for depicting responses (neo-classical responses) and money; a typical control problem. In the above concept shadow price of land is a rental price which equates with smallholder price supposing willing seller and buyer. The approach reflects land markets and transfers.

In effect, for modelling purpose and mathematically for analysis, presentation (20) can be rescheduled in a computable general equilibrium frame (CGE) using a matrix expression (below). This matrix expression has a format which will enable us to add the objective function (here biofuel) to other objectives (smallholder and landless workers) in order to retrieve a social objective function.

$$W_b(t) = \begin{bmatrix} \theta_{b,L.o} \\ 0 \\ \theta_{b,C.o} \end{bmatrix}' \begin{bmatrix} L_b(t) \\ S\ (t) \\ C\ (t) \end{bmatrix} + \begin{bmatrix} \theta_{b,f.o}p_b \\ 0 \\ -c_u \\ 0 \\ \theta_{b,z.o}r_f \end{bmatrix}' \begin{bmatrix} f_b(t) \\ e_s(t) \\ u_f(t) \\ z_d(t) \\ z_f(t) \end{bmatrix} + .5 \begin{bmatrix} L_b(t) \\ S\ (t) \\ C\ (t) \end{bmatrix}' \begin{bmatrix} \theta_{b,L,1} & 0 & \theta_{b,L,C,2} \\ 0 & 0 & 0 \\ 0 & 0 & \theta_{b,C,1} \end{bmatrix} \begin{bmatrix} L_b(t) \\ S\ (t) \\ C\ (t) \end{bmatrix} + \tag{20}$$

$$\begin{bmatrix} L_b(t) \\ S\ (t) \\ C\ (t) \end{bmatrix}' \begin{bmatrix} \theta_{b,f,L,2}p_b & 0\ 0\ 0 & \theta_{b,L,z,2} \\ 0 & 0\ 0\ 0 & 0 \\ 0 & 0\ 0\ 0 & \theta_{b,C,z,2} \end{bmatrix} \begin{bmatrix} f_b(t) \\ e_s(t) \\ u_f(t) \\ z_d(t) \\ z_f(t) \end{bmatrix} + .5 \begin{bmatrix} f_b(t) \\ e_s(t) \\ u_f(t) \\ z_d(t) \\ z_f(t) \end{bmatrix}' \begin{bmatrix} \theta_{b,p,1}p_b^o & 0\ 0\ 0 & \theta_{b,f,z,2}p_b \\ 0 & 0\ 0\ 0 & 0 \\ 0 & 0\ 0\ 0 & 0 \\ 0 & 0\ 0\ 0 & 0 \\ 0 & 0\ 0\ 0 & \theta_{b,f,1}r_f \end{bmatrix} \begin{bmatrix} f_b(t) \\ e_s(t) \\ u_f(t) \\ z_d(t) \\ z_f(t) \end{bmatrix}$$

### *9.3 Smallholders*

Technically (i.e. mathematically) the objective function of smallholders does not diver much from the above specification of the biofuel sector. However, the focus of smallholders shall be on value added from land use, instead of profits (gross margins) and constraints are different. The term “value added”, as opposed to profit with biofuels, includes returns from labour and land rents and it is based on production minus consumption (i.e. a net product. Note the local food markets and trade aspects are implicit, implying the empirical situation is given as markets are integrated, i.e. again observable). Marketed surplus serves as background. In our case returns are equivalent to monetary returns which shall be an indicator of welfare of smallholders who are consumers and food producers together. We are primarily interested in welfare changes as usually done in welfare economics. Again one can start for a depiction with a land demand function, integrate “demand below the marginal product function” and expand on the land constraint term of a welfare function. Then:

$$\Psi_b = \theta_{s,L.o}L_s + \theta_{s,C.o}S_s + \theta_{s,p.o}p_s + \theta_{s,z.o}r_f z_f + .5\theta_{s,p,1}p_s^2 + .5\theta_{s,L,1}L_s^2$$
$$+ .5\theta_{s,C,1}S_s^2 + \theta_{s,p,1}r_f z_f^2 + \theta_{s,p,L,2}p_s L_s + \theta_{b,p,s,2}p_b S_s + \theta_{b,p,z,2}p_b r_f z_f \quad (21)$$
$$+ \theta_{s,L,S,2}L_s S_s + \theta_{s,L,z,2}L_s r_f z_f +_{s,S,z,2} S_s r_f z_f$$

Equation (21) is a corresponding quadratic expression of welfare as demand on linear land demand. (Programming is another option to retrieve coefficients.) From this expansion the supply function for food and demand function for land can be derived using first derivatives to quantity (surplus):

$$q_s = \theta_{s,p.o} + \theta_{s,p,1}p_s + \theta_{s,p,L,2}L_s + \theta_{s,p,s,2}S_s + \theta_{s,p,z,2}r_f z_f = 0 \quad (21a)$$

and constrained land demand:

$$\lambda_{ls} = \theta_{s,L.o} + \theta_{s,L,1}L_s + \theta_{s,p,L,2}p_s + \theta_{s,L,S,2}S_s + \theta_{s,L,z,2}r_f z_f = 0 \quad (21b)$$

Additionally we can derive the fertilizer demand as:

$$w_s = \theta_{s,z.o} + \theta_{s,p,1}r_f z_f + \theta_{s,p,z,2}p_b + \theta_{s,L,z,2}L_s +_{s,S,z,2} S_s = 0 \quad (21c)$$

The aspect of fertilizer demand is especially important (Govereh and Jayne, 2005) for modernization, productivity increase and skill accumulation as it is indicating an up-grading of smallholders. Also we used the demand already for inclusion of the system dynamics in order to reduce the no. of control variables forwards providing subsidies. Then interactions matter. In case of land markets shadow prices equate. For the sake of simplicity we stop here, though the issue is more complex and needs further outline. The corresponding objective expression in matrix format is (22):

$$W_s(t) = \begin{bmatrix} \theta_{s,L.o} \\ \theta_{s,C.o} \\ 0 \end{bmatrix}' \begin{bmatrix} L_b(t) \\ S\ (t) \\ C\ (t) \end{bmatrix} + \begin{bmatrix} 0 \\ -c_s \\ 0 \\ 0 \\ \theta_{s,z.o} \end{bmatrix}' \begin{bmatrix} f_b(t) \\ e_s(t) \\ u_f(t) \\ z_d(t) \\ z_f(t) \end{bmatrix} + .5 \begin{bmatrix} L_s(t) \\ S\ (t) \\ C\ (t) \end{bmatrix}' \begin{bmatrix} \theta_{s,L,1} & \theta_{s,L,S,2} & 0 \\ 0 & \theta_{s,C,1} & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} L_s(t) \\ S\ (t) \\ C\ (t) \end{bmatrix} +$$

$$\begin{bmatrix} L_b(t) \\ S\ (t) \\ C\ (t) \end{bmatrix}' \begin{bmatrix} \theta_{b,f,L,2}p_b & 0\ 0\ 0 & \theta_{s,L,z,2}r_f \\ 0 & 0\ 0\ 0 & \theta_{s,S,z,2}r_f \\ 0 & 0\ 0\ 0 & \theta_{s,C,z,2} \end{bmatrix} \begin{bmatrix} f_b(t) \\ e_s(t) \\ u_f(t) \\ z_d(t) \\ z_f(t) \end{bmatrix} + .5 \begin{bmatrix} f_b(t) \\ e_s(t) \\ u_f(t) \\ z_d(t) \\ z_f(t) \end{bmatrix}' \begin{bmatrix} 0 & 0\ 0\ 0 & 0 \\ 0 & 0\ 0\ 0 & 0 \\ 0 & 0\ 0\ 0 & 0 \\ 0 & 0\ 0\ 0 & 0 \\ 0 & 0\ 0\ 0 & \theta_{s,p,1}r_f \end{bmatrix} \begin{bmatrix} f_b(t) \\ e_s(t) \\ u_f(t) \\ z_d(t) \\ z_f(t) \end{bmatrix}$$

*9.4 Landless Labourers*

### 9.4.1. Qualification

We focus our analysis to a situation of rural food markets with limited surplus potentials. This implies to look at current (pre-change without biofuel) conditions as reference. The core variable is real income as food price index; we must deflate income from biofuel. So we have to refer to welfare economics been conducted by reckoning functions as shifting (Just et al. 2002). Then we have to qualify on employment created in biofuel; note also the labour force lost in the smallholder sector (see Diagram 3) matters. We see the smallholder objective function as element of income from biofuel for rural labourers. For labour demand as representation of marginal productivity we take a quadratic exposition of objective functions (Diagram 3 gives a rural labour market). Anticipating labour supply from the smallholder sector at equivalent food prices, marginal productivities equate (it looks like demand and supply, but shadow price equate). Hereby the usual welfare approach is modified. Food demand is a function of income. Additionally, in Diagram 3 labour supply and demand are determined by a subsidy which mitigates the price increase for food. If the subsidy compensates for income losses, it would be sufficient to work with the new equilibrium with change demand.

### 9.4.2 Objective of Landless

Indeed, our welfare of landless has three aspects: (1) a likely price increase for food might affect landless' food security and the labour transferred to biofuel impacts negatively on food supply; (2) the workforce in biofuel will increase because land is converted from the smallholder sector to the biofuel sector (less labour for food production); and (3) the process is imbedded in policy (in practices: speed of land transfer and modelling is by a tax on biofuel land impeding change). As a consequence for modelling welfare implications have to be worked out with a reference to marginal productivity of labour (demand function in biofuel) and we integrate this function at different land constraints (Diagram 3). As add in Diagram 3, taxing of land reduces the propensity to employ and it has an impact on the labour market (transfer from smallholder to biofuel in land equivalents).

Notice: normally depiction of welfare (Just et al. 2002) is reckoned in partial equilibrium analysis as a function of commodity demand. Here we switch to labour demand. Economics of labouring for food should take into account food prices as well as wages. Making such deliberations and adopting similarities to static CGE modelling, labour demand can be taken as basis for welfare analysis. In our case welfare depiction, as related to income and transition policy, is solved by a food subsidy inclusion; the difference between the income at current wage (change in time) and new wage matters. To sketch the procedure, we start the mathematical analysis with a labour demand function, stating that there is a labour price (wage) and that the welfare of landless (workers) depends on employment chances and wage levels. Sure, this is a simplification of the labour demand function of the bio-fuel industry, but gives an easy specification:

$$w_{L_b} = p_{L_b} = \theta_{b,c,o} + \theta_{b,c,1} W_c^r + \theta_{b,c,2} C_b + \theta_{b,c,3} p_b [1 - f_b] \qquad (23)$$

where additionally : w: wage
W: volume (number) of employment

Actually labour demand is by biofuel farms, but the residual is wage income (expenses for labour: area und wage line): it is of interest for landless. (We have dropped an influence of fertilizer prices because we think it is marginal.) Otherwise we could state a dependency on charged fee in the slope of labour demand, been depicted in the Diagram 3.

$$w_{L_b} = p_{L_b} = \theta_{b,c,o} + [\theta_{b,c,1,o} + \theta_{b,c,1,1} f_b ] W_c^r \qquad (24)$$

An integration of the marginal labour demand function delivers a surplus (value added) function for the workforce “W”, employed in the biofuel sector.

$$S = w_{L_b} W_c - \theta_{b,c,o} W_c - .5\theta_{b,c,1} W_c^2 + \theta_{b,c,2} C_b W_c + \theta_{b,c,3} p_b [1 - f_b ] W_c \qquad (25)$$

If the (welfare) surplus per labourer is fixed (this is implied according to economic theory), at the wage w, paid, it gives income as the residual

$$w_{L_b} W_c = S - \theta_{b,c,o} W_c - .5\theta_{b,c,1} W_c^2 + \theta_{b,c,2} C_b W_c + \theta_{b,c,3} p_b [1 - f_b ] W_c \quad (26)$$

This wage payment can enter into an indirect utility function which is derived from a direct utility function for food (function, not discussed, but evident):

$$q_c^D = \theta_{c,o} + \theta_{c,1} P_F + \theta_{c,2} [S / W_b - \theta_{b,c,o} W_c - .5\theta_{b,c,1} W_c^2 + \theta_{b,c,2} C_b W_c + \theta_{b,c,3} p_b [1 - f_b ] W_c ] \quad (27)$$

Finally taking the integral of an indirect utility function which represents land less labour welfare dependent on wage and food price, welfare is established resulting in:

$$V_c^D = \theta_{c,o} P_F + .5\theta_{c,1} P_F^2 + \theta_{c,2} [\pi_b (...) / W - \theta_{b,c,o} W_c - .5\theta_{b,c,1} W_c^2 + \theta_{b,c,2} C_b W_c + \theta_{b,c,3} p_b [1 - f_b ] W_c ] P_F \quad (28)$$

Before we can enter his expression (28) into a treatable objective function, similar to the above of biofuel and smallholders (now for landless), it has to be further approximated. (For the moment it contains interactions, elements of multiplication, which go beyond a feasible depiction in a quadratic outline). Equation (28’) is a compromise. However, finally retrieving coefficients, the explicit recognition of the interdependence of the indirect utility of landless workers as dependent on performance of the biofuel and food price can be covered by the equation (28’) for welfare:

$$\begin{aligned} V_c^D = {} & \theta_{c,o} P_F + .5\theta_{c,1} P_F^2 + \theta_{c,2}[\theta_{b,c,5} L_b + \theta_{b,c,5} C_b + \theta_{b,c,5} C_b p_b^o[1 - f_b^o] P_F - \theta_{b,c,o} W_c P_F - \theta_{b,c,2}[ \\ & W_c^o C_b P_F + P_F^o W_c C_b + C_b^o P_F W_c ] + \theta_{b,c,3}[p_b^o[1 - f_b^o] W_c ] + p_b^o[1 - f_b] W_c ] P_F + p_b^o W_c [1 - f_b ]] P_F ] \end{aligned} \tag{28’}$$

In this presentation the workforce size (W: employment) has to be further explained because we want a function our stock suggested variables. Keeping things simple, we might assume proportionality between labour and land occupation. Then the land in biofuel substitutes the labour variable.

$$\begin{aligned} V_c^D = {} & \theta_{c,o} P_F [1 - z_d] + .5\theta_{c,1} P_F^2 [1 - z_d]^2 + \theta_{c,2}[\theta_{b,c,5} L_b + \theta_{b,c,5} C_b + \theta_{b,c,5} C_b p_b^o[1 - f_b^o] P_F \\ & - \theta_{b,c,o} \rho_{b,w} L_b P_F 1 - z_d] - \theta_{b,c,o} \rho_{b,w} L_b P_F 1 - z_d] - \theta_{b,c,2}[W_c^0 C_b P_{F[} [1 - z_d] + \rho_{b,w} L_b [P_F^o [1 - z_d] C_b \\ & + C_b^o P_F [1 - z_d]]] + \theta_{b,c,3}[p_b^o[1 - f_b^o] \rho_{b,w} L_b] + p_b^o[1 - f_b] \rho_{b,w} L_b] P_F [1 - z_d] + p_b^o \rho_{b,w} L_b [1 - f_b ]] P_F ] \end{aligned} \tag{29}$$

### 9.4.3 Note on food price

Representation (29) shows how welfare of a workforce (landless) in biofuel changes with the state and control variables. Finally, in a section on food price formation and dynamics we need to close the model. There are two ways to deal with food prices. (a) One can assume a liberal-import-export scheme. Or (b) a local price formation prevails. We opt for the moment for the first version as price transmission: though we think second version is more realistic; but supply must be checked. Then:

$$\begin{aligned} V_c^D = {} & \theta_{c,0,1} P_F^0 [1 - z_d] + \theta_{c,1,1} P_F^{02} [1 - z_d]^2 + \theta_{c,1,0}^* L_b + \theta_{c,2,0}^* C_b + \theta_{c,2,1}^* C_b p_b^o [1 - f_b^o] \\ & + \theta_{c,1,1}^* p_b^o [1 - f_b]^2 + \theta_{c,2,1}^* L_b^2 + \theta_{c,3,1}^* C_b^2 + \theta_{c,1,3}^* p_b^o [1 - f_b] L_b + \theta_{c,2,2}^* L_b C_b + \theta_{c,2,2}^* C_b p_b^o [1 - f_b ] \end{aligned} \tag{30}$$

Equation (30) comes with condensed coefficients. And the objective function is technically (31):

$$W_c(t)=\begin{bmatrix}\theta^*_{c,1,0}\\0\\\theta^*_{c,2,0}\end{bmatrix}'\begin{bmatrix}L_b(t)\\S\ (t)\\C\ (t)\end{bmatrix}+\begin{bmatrix}0\\0\\0\\\theta_{c,0,1}P_F^0\\0\end{bmatrix}'\begin{bmatrix}f_b(t)\\e_s(t)\\u_f(t)\\z_d(t)\\z_f(t)\end{bmatrix}+.5\begin{bmatrix}L_s(t)\\S\ (t)\\C\ (t)\end{bmatrix}'\begin{bmatrix}\theta^*_{c,2,1}&0&0\\0&0&0\\0&0&\theta^*_{c,3,1}\end{bmatrix}\begin{bmatrix}L_s(t)\\S\ (t)\\C\ (t)\end{bmatrix}+$$

$$\begin{bmatrix}L_b(t)\\S\ (t)\\C\ (t)\end{bmatrix}'\begin{bmatrix}\theta^*_{c,1,3}p_b^o&0&0&0&0\\0&0&0&0&0\\\theta^*_{c,2,1}&0&0&0&0\end{bmatrix}\begin{bmatrix}f_b(t)\\e_s(t)\\u_f(t)\\z_d(t)\\z_f(t)\end{bmatrix}+.5\begin{bmatrix}f_b(t)\\e_s(t)\\u_f(t)\\z_d(t)\\z_f(t)\end{bmatrix}'\begin{bmatrix}\theta^*_{c,1,1}p_b^o&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&\theta_{c,1,1}P_F^{02}\\0&0&0&0&\end{bmatrix}\begin{bmatrix}f_b(t)\\e_s(t)\\u_f(t)\\z_d(t)\\z_f(t)\end{bmatrix}$$

## 10 Social objectives as function

### *10.1 Discussion*

Finally the three individual objective functions of sectors are added (for the moment no weights are applied) and we get social welfare. Food security is in the smallholder and landless objective recognized. Thence we only deduct costs of the government for extension and land transfer (already done above in 20 and 22). Still, a decisive problem is to distinguish between private and public costs; some remarks are to be made on decisions of the private sectors and government. This concerns especially the mode of optimization and ways how decisions are made in biofuel, i.e. in conjunction with government use of instruments. Since the expansion of biofuel could be considered an investment plan, this would require dynamic optimization on private side and it would be a dynamic game. We skipped that and see no real anticipation of forward instrument planning. In the management benefits of capital stock are addressed as improving profits (not modelled as investment plan). A simple anticipation is to take a percentage of capital as depreciation. Such cost calculations allows for a coincident specification of net benefits in the above function as we state:

$C^n = (1-\nu)\ C$

This applies instead of C for capital stock variables being fully put into net present values.

### *10.2 Technical Depiction of the Social Objective (Welfare) Function*

Technically if we add functions (20, 22, and 31) in a society approach such as (32) prevails

$$W\;(t) = .5\begin{bmatrix} L_b(t) \\ S\;(t) \\ C\;(t) \end{bmatrix}' \left[ \begin{bmatrix} H_b^{111} & H_d^{112} & H_b^{113} \\ H_b^{121} & H_b^{122} & H_b^{123} \\ H_{bb}^{131} & H_b^{132} & H_b^{133} \end{bmatrix} + \begin{bmatrix} H_s^{111} & H_s^{112} & H_s^{113} \\ H_s^{121} & H_s^{122} & H_s^{123} \\ H_s^{131} & H_s^{132} & H_s^{133} \end{bmatrix} + \begin{bmatrix} H_d^{111} & H_d^{112} & H^{113} \\ H_d^{121} & H_d^{122} & H_d^{123} \\ H_d^{131} & H_d^{132} & H_d^{133} \end{bmatrix} \right] \begin{bmatrix} L_b(t) \\ S\;(t) \\ C\;(t) \end{bmatrix} + \begin{bmatrix} L_b(t) \\ S\;(t) \\ C\;(t) \end{bmatrix}'$$

$$\left[ \begin{bmatrix} H_b^{211} & H_b^{212} & H_b^{213} \\ H_b^{221} & H_b^{222} & H_b^{223} \\ H_b^{231} & H_b^{232} & H_b^{233} \end{bmatrix} + \begin{bmatrix} H_s^{211} & H_s^{212} & H_s^{13} \\ H_s^{221} & H_s^{222} & H_s^{23} \\ H_s^{231} & H_s^{232} & H_s^{33} \end{bmatrix} + \begin{bmatrix} H_d^{211} & H_d^{212} & H_d^{213} \\ H_d^{221} & H_d^{222} & H_d^{223} \\ H_d^{231} & H_d^{232} & H_d^{233} \end{bmatrix} \right] \begin{bmatrix} f_b(t) \\ u_f(t) \\ e_s(t) \end{bmatrix} + \begin{bmatrix} H_b^{131} & H_b^{312} & H_b^{313} \\ H_b^{321} & H_b^{322} & H_b^{323} \\ H_b^{331} & H_b^{332} & H_b^{333} \end{bmatrix} +$$

$$\begin{bmatrix} H_s^{311} & H_s^{312} & H_s^{313} \\ H_s^{321} & H_s^{322} & H_s^{323} \\ H_s^{331} & H_s^{332} & H_s^{313} \end{bmatrix} + \begin{bmatrix} H_d^{11} & H_d^{12} & H_d^{13} \\ H_d^{21} & H_d^{22} & H_d^{23} \\ H_d^{31} & H_d^{32} & H_d^{33} \end{bmatrix} \begin{bmatrix} f_b(t) \\ u_f(t) \\ e_s(t) \end{bmatrix} - \begin{bmatrix} m_{f,g} \\ c_{tl,g} \\ c_{t_{e,g}} \end{bmatrix}' \begin{bmatrix} f_b(t) \\ u_f(t) \\ e_s(t) \end{bmatrix} or$$

$$W(t) = .5Y'(t)H_1\;Y\;(t) + Y'(t)\;H_2\;u\;(t) + i_3'\;H_3\;u\;(t) \qquad (32)$$

It is a vector and matrix outline and basis for system welfare depiction giving a consecutive control problem. And it works with the reduce number of control variables accordingly specified in equations (17a/b). Transaction costs are external but fit into the concept easily, and they can be simulated.

## 11 The Control Problem

The objective (32) and system dynamics (18') can be combined as Hamilton function (within dynamic constraints in 18 there is land); and, hence, a control problem can be stated as usual (Tu, 1991):

$$H(t) = \{\exp(it).5Y'(t)H_1\;Y\;(t) + Y'(t)\;H_2\;u\;(t) + i_3'\;H_3\;u\;(t)\} + \lambda'\;[M_1Y\;(t) + M_2u\;(t) + c\;(t))] \quad (33)$$

which gives land transfer strategies and a steady state if the change becomes zero. Using dynamics optimization calculus a Hamilton equation delivers three conditions in case of the dynamic control:

$$\partial H(t)/\partial Y = H_1\;Y\;(t) + H_2'\;u\;(t) + M_1\lambda_1 = -\dot{\lambda}_1 \qquad (33a)$$

$$\partial H(t)/\partial u = H_2\;Y\;(t) + H_3'\;i = 0 \qquad (33b)$$

$$\partial H(t)/\partial \lambda = M_1Y\;(t) + M_2u\;(t) + c\;(t) = \dot{Y}\;(t) \qquad (33c)$$

Since we are now in a well-known frame of optimization by taking derivatives and analytics are obvious, it remains technical to state conditions. System (33) can be solved as differential equations. As usually done, one can offer also a steady state solution claiming change variables are zero in the end. Other specifications can work with discrete control (Chow, 1997). As regards to food security it is yet implicit in welfare, not a plain constraint; but other version can impose thresholds.

## 12 Application and Coefficient Retrieving

In order to apply the model empirically most needed coefficients can actually be retrieved already from ordinary CGE modelling if sectors are streamlined. Though CGE modelling is primarily not dynamic, simulations will provide response functions to exogenous drivers. In a framework, for CGE the variables are exogenous; then in our dynamic model they become endogenous. Problems will emerge concerning non-linearity which needs approximation and eventually iterations because the basis for calibration of the CGE; usually CGE modelling is done at marginal changes whereas dynamic model can exceed marginal changes. It is important to streamline the corresponding comparative statics with the dynamic modelling based on similar crops and labour economy aspects.

For both, the coefficients in the objective function and the system dynamic coefficients, a problem will be to find the right level of aggregation. For instance choices to take a village, district or regional level will change modelling style. Especially labour requirements and food demand functions will be designed according to scaling of the model. Since, the food security of thousands of regional inhabitants are concerned it also needs a decent analysis of the virtual land-food demand as expressed of land, potentially converted, and the local conditions for self-sufficiency have to be checked.

## 13 Summary

This paper demonstrates how control theory can be used to specify a dynamic adjustment concept to biofuel expansion which cares about food security, maintenance for soil fertility, extension in smallholder sector (for productivity increase) and offers scope for income growth. Control variables such as a land tax, food subsidy for landless, extension and controlled land transfer are explicitly stated in conjunction with stock variables (land use, comparative advantage and skills). Finally it is indicated how the model gets objective functions from welfare analysis and how to solve it.

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## 14 List of Abbreviation used:

stock variables:
S: skills
C: comparative advantages
$L_b$: land (l is redistribution) in the large-scale (biofuel) sector
$L_s$: land in the small-scale sector
$L_t$: total land
$F_g$: fallow grassland

flow variables:
$e_s$: education
f: fertiliser
$z_f$: subsidy on fertilizer
$f_b$: fee (tax) on land
$z_d$: food subsidy
$c_s$: transaction costs

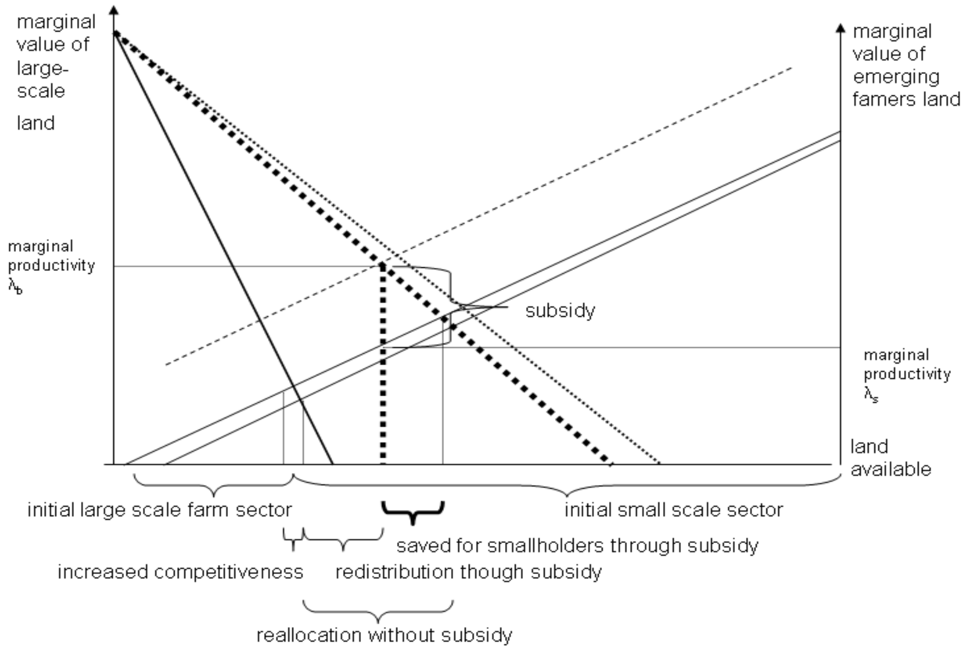

**Diagram 1: Land market**

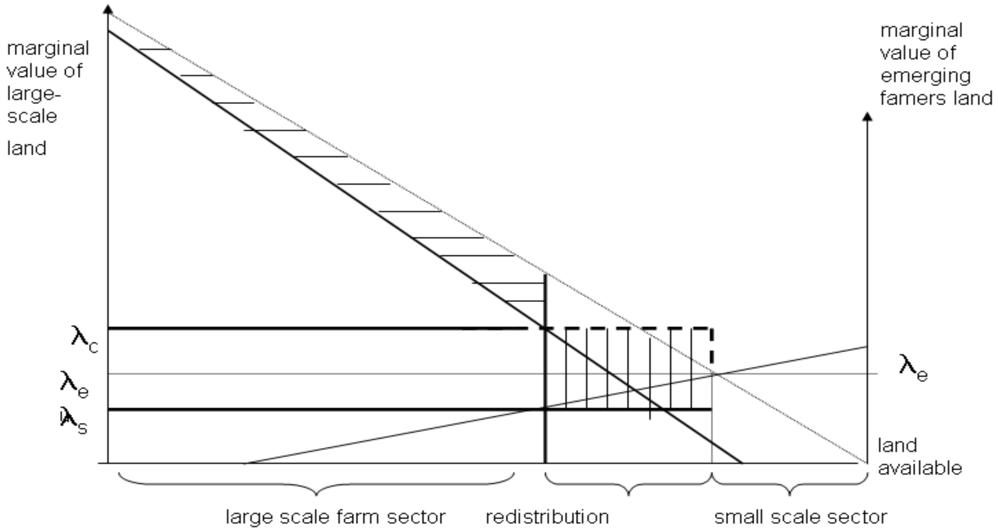

**Diagram 2: Marginal productivity functions on land market, instrument variable and partial welfare**

**functions of the bio-fuel and smallholders**

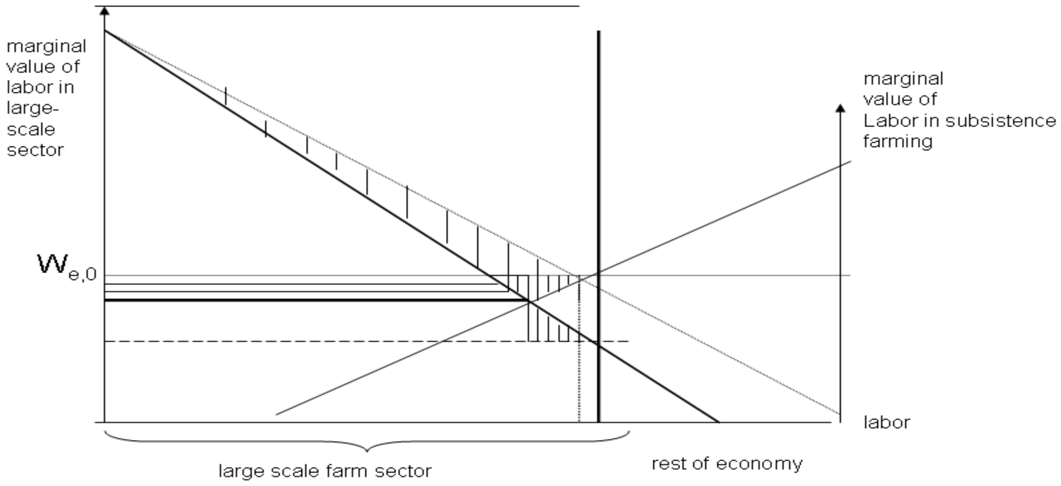

**Diagram 3: Welfare Analysis of the derived from the labour demand**