MODELLING ECONOMIES OF SCALE, ENERGY USE AND FARM SIZE TO REDUCE GHG: ON CONTRASTING "HIGH-TEC"-AGRICULTURE WITH LABOUR INTENSIVE FARMING

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ABSTRACT

Questions on farm structures (such as superiority of large farms) are typically linked to economies of scale. Economies of scale are normally a matter of investments in energy consuming technologies (large machinery). In contrast there is the issue of remaining prevalence of labour intensive, small farms (meant to be inferior); but which are less energy intensive. We see a revival in theoretical and policy debates on pathways of agricultural development concerning energy use. We analyse, how one can develop an approach that includes incentives to save energy and produce less GHG, and develop a framework of coexistence of farm types.

Keywords: Green house gas emission, farm structure, policy modelling

1 INTRODUCTION

The discussion on green house gas (GHG) emission has reached the agricultural sector (Fish et al., 2008). With structural change in agriculture over the last decades labour intensity has been reduced and energy intensity has been increased (Pimentale, 1980). The use of fossil energy is nowadays a main source of power in agriculture. Instead of using renewable energy produced within the sector, famers heavily rely on fossil energy. There is even a discussion whether the production of ethanol is really energy efficient because it needs a lot of fossil energy under current technology conditions (Schmitz et al. 2007). By using fossil energy agriculture increased its labour productivity and assured the survival and income of those farmers who modernized and wanted to stay in business. In particular, the discussion on economic efficiency of large, energy intensive vs. small, labour intensive farms (Shankar et al, 2003) in transition countries has renewed the proposition that modernized farms are more competitive. In contrast small farms emitting less carbon and green house gases have become less competitive and farmers are compelled to migrate to other sectors as a result. But, by its structural change, the overall critic on agriculture as an emitting sector is increasing. A question is how can modelling of decision making on energy use and policy instruments help to mitigate the GHG emissions?

There seem to be individual level and societal level problems with energy use in agriculture. The ecological-economics literature is questioning the advantage of large farms. Literature based on Georgescu-Roegen's hypothesis (Martinez-Alier, 1997) of "peasant farming as being advantageous for sustainable farming" says: yes, there is an advantage for small farms; and in particular because of recycling and minimal use of fossil energy small, labour intensive

farms should be prioritized as development path in an environment. This type of farming seems to seek to better minimize GHG emissions compared to large, energy intensive farms. Foremost since, emissions from agriculture, farm structures, and nutrient balances have become an issue, as well as measures are sought to reduce emissions (Lal, 2004). In contrast large farms fear to loose competitiveness if they are confronted with energy balances. We will contribute to the debate by relating emissions to the farm size and farmers' objective as well as to seek a compromise. Furthermore we will make suggestion how to model farms more correctly with respect to behaviour and emission portraying and, in particular, we will do that by contrasting a "peasant" and a "modern farm" sector. For instance, objectives, technologies, structures and constraints may be different for peasants and modern farmers.

However, we do not say that a sector is "better" per se in avoiding GHG emissions. The argument of the paper is towards co-existence of both sectors which is enabled by a policy which subsidies the "peasant sector" for mitigation and which taxes the modern sector for emission. In the paper we work with a dual farm sector in which a small, labour intensive farm sector and a large, energy intensive sector compete for land. The objective is to show how policy instruments such as taxes for energy use and technologies as well as subsidies for labour intensive farming activities and recycling can redirect the overall behaviour within a farming sector and between farms. The policy aim anticipated is that the policy instruments "tax" and "subsidy" shall reduce the use of fossil energy and hence reduce GHG emission.

The paper is a conceptual paper and it will show a new pathway for concise modelling of a dual farm structure based on farm decision making tools. Tools are otherwise, fairly well known such as linear programming of economies of scale and quadratic programming. The plea is that sectors should be firstly separately modelled to get a structural view on GHG emissions composed of types of farm operation and then secondly combined. However, the author is fully aware, that in reality there is a spectrum of technologies and the use of fossil energy vs. recycling can be applicable in individual case on both sides of the line. For instance, a modernized farmer may claim that he is more energy efficient within his technologies than a peasant applying these technologies and also recycles; or he may say his tractors run with renewable energy (rape seed). But this is not the issue. Things may be exceptional. The issue is whether a single type of technology choices should dominate the structural appearance of a sector with respect to energy use. In principle it is hypothesized that small, less fossil energy using farms should have a chance. The paper works with the hypothesis that less (labour) productive farms have a disadvantage on the land markets and

“normally” they would be squeezed to a niche operation, though their labour is needed because it substitutes energy. If no positive externality (less GHG emission) is awarded the small farm type might extinguish. The question is to what extent does it contribute to the overall GHG balance and should be promoted?

The paper discusses policy tools to identify optimal sizes of farm operations along ecological concerns, which are more closely linked to the ecological impacts of farming in a first layer. To do so, we integrate ecology concerns as a reference to different technologies requiring different levels of labour in a second layer of policy analysis. In this framework, taxing and subsidization will be outlined. Taxes will be differently assigned to technologies with an aim to reduce energy intensity, though we will show how to test the income effects. Subsidies will be paid for labour in recycling. From another angle a moderate position is taken with respect to sustainable farming. Again the co-existence is given priority because it is argued that raised taxes can be used to subsidize less GHG emitting farms for which we need a common tax basis.

However, this is not a pure discursive or politically oriented paper, which looks for arguments for small farms; rather a paper which suggests a concept of how to model the co-existence of small, labour intensive and large energy intensive farms. The immediate question is how to model the aspect of farm size and declining average costs in case of scale economies and to decipher appropriate technologies. For the sake of instrument and policy design we need a modelling concept of responses to instruments and their optimization which will be provided.

Our approach draws on the concepts of linear programming of scale economies and recycling as well as positive quadratic programming with a reference to maximum entropy (Paris and Howitt, 200). In particular, we suggest combining these methods with the principal-agent-theory (Richter and Furubotn, 1996). As a further issue, involved in the following discussion and motivation of the research, we have to think, moreover, on the pressure the agricultural sector may undergo in future: I.e. in the opinion of the author it is not sufficient to prove that ecologies of scale exist by modelling them, which may justify a certain level of “necessary” energy input in agriculture. Rather we take a normative approach and provide cost minimization. This approach, for which the conceptual outline will be given, is necessary to find a trigger that enables a reduction in fossil energy use. A reduction in energy use should be linked to substitution options in the current basket of technologies and enable energy savings at reasonable costs. From a normative point of view, this would mean that a certain com-

position of farm types (farm structure) could enable a cost minimal achievement of certain GHG emission targets. In addition, it does not seem to be too realistic to reduce fossil energy use purely as constraining farming. To a large extend the survival of the sector and eventually food security is concerned. To depart from intensive agriculture at all is not conducive for all farmers. For instance, some European farmers have enjoyed high labour productivity and observed the advantage of highly mechanized agriculture; they may not go back. But counterparts could be find who take over and deploy more labour. So what are interactions?

2 METHOD

2.1 Reference and aims

There is an intensive discourse on how to model farm supply and structural changes through programming models, to cope with different technologies through flexible functions, and to integrate different types of technologies in supply models through addressing heterogeneity of farms (Heckelei 2002). It is not the intention of this paper to repeat the discourse (or contribute to further advances, for instance, for scenario building, etc.: Theron et al, 2009); rather a different pathway is suggested which may enable us to adopt another string for policy analysis, for example, to specify policy instruments, such as those build on simple principal-agent theory (Richter and Furubotn, 1997). Through fairly simple modelling of farmer responses we seek to accomplish feasible reactions to policy instruments. We want to integrate principal agent theory into policy analysis at a modest level of analytical sophistication. Moreover, the analysis shall be easily linkable to energy use. One important issue, tackled, is the co-existence of small-scale, labour intensive farming with large-scale, energy intensive farming. However, the aspect of the coexistence of small and large farms has to be tackled with respect to energy use and recycling of nutrients, increased labour intensity, etc.; and we look at modes to get medium sized technologies. Further note the paper is more a conceptual outline than a ready made model. In this regard the author does not want to endeavour in very sophisticate methods, rather we start with a simple presentation of economies of scale through programming .

2.2 Programming

As said the aim is to keep the approach in a mode that policy becomes easily retrievable from the structure of farms. A special mode of the linear programming method is adopted from Köhne (1965). For the integration of economies of scale modelling linear programming offers

a tool to deal with economies of scale by using sequential programming. We first present this tool and then discuss it in conjunction with the problem of energy efficiency. However, to keep the subject operational the approach is based on well-known rules of linear programming LP. Basically for energy use linking and technology adoption, programming means that most problems must be kept linear. In Figure 1, a case is outlined where we distinguish between cow rearing technologies which are discretely given as 0 to 20 cows, 21 to 40 cows and 41 to 60 cows. Note this is also the original example of Köhne (1965). It shows a case of milk production in which more than sixty cows were a large farm (today it maybe 200 cows, however, now 200 cows can be dealt with at the family level using heavy machinery). The least cost production system can not be ultimately chosen in terms of economies of scale. The clue is that, in order to get the least cost activity in a programming, other activities are to be chosen before. The highest gross margin is only achieved if activities with higher average costs (lower gross margins) are conducted "before" an achievement of lowest costs. The LP algorithm supports this. Reduced achievements in economies of scale are part of the programming because other constraints have to be considered simultaneously. Hereby we approximate a typical scale problem by a rather simple tool and can depict the functions in discrete steps; whereas it depends on the skills of the investigator to linearize most appropriately.

Figure 1: Tableau of Linear Programming

Gross Margin unit			1000	0	1800	0	1850
Capacities	P_0		P_1 0 - 20 cows	H_1	P_2 21-40 cows	H_1	P_3 11-60 cows
Labor other restirciton	3600 b_2 ... b_m	≥ ≥ … ≥	100	-5 0	30 . . .	0 O	20 . . .
Technology I cows II cows III cows IV cows V cows	 20 0 0 0 0	 ≥ ≥ ≥ ≥ ≥	 1 -1	 20 -20	 1 -1	 20 -20	 1

Source: Steinhäuser et al. 1996

For energy use aspects the distinction of technologies as discrete steps has the advantage that we can identify technologies with their particular GHG emission and calculate the conse-

cutive distributions of these technologies to emission. This also means that emissions can be addressed by policy, for instance, taxes which can halt processes to further intensification in energy intensive technologies. Note the farm will not choose automatically the least cost activity in terms of economies of scale, i.e. technology with highest emission. Since the other constraints will determine the size of operation as been driven by the most binding constraint, labour and land availability are aspects that can modify decisions. As a consequence we can model small and large farms (for the moment as categories). These farms differently use external energy (see next). Additionally we can use observations from farm behaviour.

For sure, farmers' optimizing along the above tableau does not care about energy aspects. But embedded energy levels are retrievable though different with technologies. For the sake of empirical analysis it is important to contrast farms who have chosen strong investments in machinery and who did not. It is interesting to know that, from observation, types of farmers can be immediately distinguished. At the same time we need a generalization. A possibility is to take a model with a generalized technology and supplement it with observations.

Another aspect which can be modelled is the analogy between economies of scale and ecologies of scale. The above modelling is a primal modelling. Energy use is either calculated from the outcome or it imposes a further constraint. In a dual analysis the energy use can be minimized given a certain income. Hereby new opportunities may emerge. The essentially aspect is that the programming provides an "observation" on technology choices. However, we proceed stepwise and explain furthermore that objectives and perceptions of farms differ as well as seek to generalize for the specific types of farms.

2.3 Energy Constraints and Generalized Form for Large Farms

Using the scheme of programming above, the aspect of energy use has to be re-integrated into programming itself. We start with modernized, energy intensive large farms. Then we enter into the sphere of energy needs and potential energy use as constraints. A question is how do we deal with energy as input? For instance, what are the substitution options in terms of alternative production activities and how do we deal with fixed amounts coming in with congealed energy from machinery. As been said the above, linear programming is discrete on technologies which enables us to have several activities (variables) associated with different emissions. To keep it simple, one can assume that external fossil energy use of agriculture is directly linked to CO_2 emission, either directly at farm level or indirectly from energy/CO_2 coefficients involved in the production of equipments. For a first approach on policy

implantation it could be stated that farmers might get a quota of emission rights, i.e. a quota of energy embodied in machinery, use of diesel, electricity, etc. and running the farm within that limit, i.e. if they want to produce along economies of scale the have to allocate the right. A second approach is a tax on energy. We explicitly put the tax on the change in technology and the taxing is on incremental GHG emission. Then the question expands along different types of machinery, farm equipment and measures that constitute modern energy intensive farming. Note, the energy use could be calculated in diesel equivalents. From the previous economies of scale analysis, suggested in the linear programming frame, we can resume internal categories or incremental steps of the choices on technologies. They prevail and constitute as constraints the technology matrix. We also include this as a constraint c_t in system (1) Note, the constraints are internally used and apply differently between small-scale and large scale farms. We can then use them later as a distinction for small and large scale farm energy use intensity.

$$\begin{aligned} &\text{Max } \{ [p-u]' q - t'h\} \qquad (1)\\ &A_{11} q < c_s \\ &A_{12} q < c_l \\ &A_{13} q - Z_{11} h < c_e \\ &Z_{11} q - Z_{12} h < b_t \end{aligned}$$

where c_1: standard constraints
c_e: energy constraints to be met
c_l: land constraint to be met
b_e: threshold values for economies of scale
q: production activites
h: variables controlling economies of economies of scale
t : tax
p-u: gross margin

To be more explicit on the issue of taxing incremental steps, this formulation includes the potential for economies of scale as a variable “h”. In the classical model (Köhne, 1965) steps are without costs; they serve purely as additional variable from a programming point of view. However, taxes can be raised on emission increase through steps and they are later to be chosen based on response functions delineated. This implies that unit costs for farmers with different technologies can be directed by a government that seeks to charge different taxes in different technologies. For a farmer it means augmenting his production implies different tax levels because he emits GHG. The government has the option to escalate tax levels.

Concerning the programming with switching technologies, as discussed so far, it is restricted to a typical farm”. However, as positive quadratic programming (Paris and Howitt, 200) has show we can generalize and receive flexible response functions which would mean also

response functions to taxes at different levels. Two aspects are involved if a tax on technologies is imposed: (1) technology choices are redirecting the energy consumption and (2) competitiveness on the land market is changing. As will be shown soon the flexible version of the programming gives demand functions on constraints and this will enable us to use the programming as prototype for establishing smooth behavioural equations of large farms who seek to use economies of scale.

The following outline briefly explains the method. Technically programming combines dual and primal solutions. Correspondingly we are able to specify the dual problem of minimizing the shadow prices. Minimizing shadow prices later refers to demand functions of inputs. For the moment the result of the optimization based on programming is given in the outline (2):

$$\begin{aligned} \text{Min} \quad & \{ c_e' \lambda_t + c_e' \lambda_l + c_e' \lambda_e + b_e' \lambda_s \} \\ & A_{11}' \lambda_t + A_{12}' \lambda_l + A_{13}' \lambda_e + A_{14}' \lambda_s > p - c \\ & 1' \lambda_t + 1' \lambda_l + Z' \lambda_s > -t \end{aligned} \tag{2}$$

where $\lambda_{l,t,e,s}$: shadow prices

Note that our farm model works with an imposed energy constraint so energy demand prevails and a shadow price are given. Also optimized farm activities and shadow prices for traditional constraints are internally derived. A next step is to translate the programming results into functions. For the moment and here we need only to sketch how the procedure works because it is established as Maximum entropy ME (Paris and Howitt, 2000). That suggested method use positive mathematical programming. As result one obtains a quadratic cost function (6)):

$$P(q,h,\lambda)=[p-u]'q-t'h-.5[q,h]'Q_1[q,h]+[q,h]'Q_2[\lambda_s,\lambda_e,\lambda_t,\lambda_f] +.5[\lambda_s,\lambda_t,\lambda_f,\lambda_e]'Q_3[\lambda_s,\lambda_t,\lambda_f,\lambda_e] \tag{3}$$

The interesting topic is now that this function contains the technology switches. Some remarks are necessary concerning observation on technologies and modelling with technology switches (constraints). (1) As been outlined by Howitt and Paris (2000), the flexible form of a quadratic modelling allows a delivering of marginal values. (2) A divergence between observations and internally calculated shadow prices or unit costs, respectively, is possible. (3) The limitations of linear programming with respect to discrete technologies and non-equal conditions can be overcome through ME through detection of generalized coefficients. Technically, in principle, the same can be applied to technology switches in economics of scale and some steps actually must not be fully met; rather for the empirical foundation we have to seek thresholds to include additional observations on technology choice (i.e. to

distinguish those step met and those not met in economies of scale). Setting some balances to nil and looking for several farmers we can obtain a sector function. As a practical note: For observations on technology (for example on the size of tractors which are chosen according to the size of the farm but also with respect to expanding the size by additional renting in of land to meet the economies of scale of machinery, i.e. bigger tractors and combines), equality balances can be re-introduced (otherwise not). Note "h" is an artificial variable of technology switches which is, however, a measure for energy use. This enables a better representation of the energy demand equation that counts for the tax implementation. Taxes must not be uniform based one single energy equivalent; rather they can become progressive (stepwise) with technologies. Tax functions become smooth and stepping though they are still addressing technology choices of farmers. This is important because technology choices as be outlined are part of decisions for farm size and structure.

2.4 Farm Economics for Small Farms

In principle and at least in an analogous procedure, but now for a small-scale farms, programming could give us a similar outlay as in the large-scale case. Though note that there is a major difference in the design of the programming. Since we want to model the structural aspects of a having a dual farming sector of small and large farms and seek policies that help us to shift from energy intensive large farms to labour intensives small farms, the small-scale sector should be distinguishable from the large scale sector. The distinction is on recycling activities and labour devoted to it. Note the discussion is not on individuals and why a farmer is a large scale or small-scale type or that he has a choice to be big or little. We simply assume that the different farms exist. Also we want to avoid a discussion on motives.

For the small scale sector we simply presume that farmers are recycling organics by knowing particular technologies, are devoting labour to recycling, and that no economies of scale prevail; rather labour intensive technologies are prevailing. Especially, recycling is a costly internal activity in terms of labour requirements, which delivers, for instance, soil nutrients from animal wastes, crop residues as organic fertilizer, etc.; i.e. we are especially looking at mixed farms. It also means that from an economic point of view, activities of recycling nutrients may look more expensive than their purchased counterparts if we take wage rates, but they may fit into the labour economy if we take family labour and shadow prices. I.e. we do not take the wage or labour productivity of large farms as reference, respectively. Recycling as a labour requesting activity can be introduced as an internal activity delivering nutrients (nitrogen) from harvesting organic matter and as substituting mineral fertilizer. This

saves a lot of fossil energy. The saving comes with labouring for recycling. So recycling must be no mechanized activity. In modelling it is assumed that nutrients do not have financial costs, per se; no value appears in the objective function, but opportunity costs. As a costly activity, recycling negatively contributes to the farm objective by binding labour for sales activities; though expenses for mineral fertilizer are saved. Assuming labour surplus poor farmers may work hard because they can not afford mineral fertilizer and machines. In this regard they are ecologically more effective. But, eventually, only if we assume that a government can subsidize small farm activities of recycling pay. Note that recycling means less fossil energy use, for instance for nitrogen fertilizer, etc. A similar programming approach (4) on optimization of smallholders, comes now with recycling; it is a first steps to achieve

$$\text{Max } \{ [p-u]' q - [u-s]' r\} \tag{4}$$
$$A_{11} q + A_{21} r < c_1$$
$$A_{12} q + A_{21} r < c_t$$
$$A_{13} q - A_{23} r < n_r$$

where c_t: standard constraints
c_l: land constraint to be met
n_r: nutrients constraint in recycling
u: unit costs in recycling
s_l: subsidy
r_s: recycling activity

a corresponding generalized behavioural functions (5). For a re-formulation, as a flexible function which can accommodate policy instruments, we get, as indicated above in the same vein, positive quadratic programming (and ME). Programming is now for small scale technologies; i.e. a functional representation of a profit function of a small-scale sector. This profit function (5) takes into account subsidies and gives values for the constraints as shadow prices.

$$P(q,r,\lambda)=[p-c]'q-[c-s]'r-.5[q,r]'Q_1[q,r]+[q,r]'Q_2[\lambda_s,\lambda_n,\lambda_f]+.5[\lambda_s,\lambda_n,\lambda_f]'Q_3[\lambda_s,\lambda_n,\lambda_f] \tag{5}$$

This profit function can be used to get a response function subject to the subsidy on recycling of nutrients and hence we can portray how to reach less purchase of artificial fertilizer.

3 Application of Farm Models for Response Functions

The working idea is now that demand functions for energy and carbon dioxide emission, as well as nutrient recycling and energy saving, respectively, can be derived. These functions shall depend on taxing/subsidies of technologies and we want to link it to farm technologies.

3.1 Large Farm Responses

Shadow prices give demand functions (6), for instance, delineated from profits of large farms. They are the first derivatives of the profit function (3). Further note that the linear "technology" assumption still matters, i.e.: $A_{11}\, q = c_1$ and $A_{12}\, q = c_e$ are representing balances. Then, by the use of derivatives and the generalization of technologies (applied on representative farms which even can vary for agronomy criteria: Röhm and Dabbert, 2003)), we can offer analytical solutions for the optimization with taxes. Especially a relationship between shadow prices, energy constraints and activities, based on distinct technologies, can be retrieved. For instance, the relationship (6a) depicts the constraint (demand) for energy (carbon emission) as shadow price dependent. Various further constraints (for land 6b, etc.) are "explained" by the derivative of the 'cost' function:

$$\delta P(q,h,\lambda_s,\lambda_e,\lambda_t,\lambda_f)/\delta\lambda_e = Q_{221}q + Q_{321}\lambda_s + Q_{322}\lambda_e + Q_{323}\lambda_t + Q_{324}\lambda_f + Q_{212}h = c_e \quad (6a)$$

$$\delta P(q,h,\lambda_s,\lambda_e,\lambda_t,\lambda_f)/\delta\lambda_l = Q_{211}q + Q_{311}\lambda_s + Q_{312}\lambda_e + Q_{313}\lambda_t + Q_{314}\lambda_f + Q_{222}h = c_l \quad (6b)$$

$$\delta P(q,h,\lambda_s,\lambda_e,\lambda_t,\lambda_f)/\delta\lambda_f = Q_{231}q + Q_{331}\lambda_s + Q_{332}\lambda_e + Q_{333}\lambda_t + Q_{334}\lambda_f + Q_{232}h = c_f \quad (6c)$$

…

Moreover, the inversion of the matrices delivers a behavioural equation such as.

$$\lambda_e = Q_{31}\, q + Q^*_{32}\, c_l + Q^*_{33}\, c_e + Q^*_{34}\, c_t + Q^*_{34}\, c_t + Q^*_{35}\, b_e + Q^*_{45}\, h \quad (7a)$$

Firstly, from (7a) a shadow price for energy constraints can be calculated. Secondly it shows how this value depends on the choices q and h. I. e. the profit can be optimized to q and h and finally this will create a relationship between prices (or gross margins respectively) and quantities, including taxes and constraints on the technologies.

$$\lambda_e = Q^{**}_{31}\, [p\text{-}c] + Q^{**}_{31}\, t + Q^{**}_{32}\, c_l + Q^{**}_{33}\, c_e + Q^{**}_{34}\, c_t + Q^*_{35}\, b_e \quad (7b)$$

This is important for policy design. For the later policy analysis we have to show that the tax can be translated into prices of farm energy if this energy comes as an alternative; i.e. to purchase energy vs. internal sources of the farm sector. The same can be done for farm labour, land, etc. The interesting aspect is that the separate optimizations provide necessary conditions to be met in a second layer of sector optimization of energy use change as shared between small and large farms (chapter 4). This second layer corresponds to incentive constraints like in principal agent approaches (Richter and Forubotn, 1996). Our first layer optimization characterizes the behaviour of farmers with respect to existing or imposed energy constraints and taxes. But it is also a response function to incentives. The availability

of energy for individual farms may be not constraining; rather farmers presume that energy can be purchased from market. Alternatively the government can introduce environmental budget on GHG. We can take the energy price or the shadow price as calculations for the change in profitability. Importantly, since we want to model the competition of farm sectors, a similar opportunity to derive demand functions, exists to depict the land constraint as a land demand. We use the partial land equation from the set of the equations above and re-specify:

$$Q^{l}_{21}[p-u_e]+Q_{341}\lambda_s+Q_{342}\lambda_e+Q_{343}\lambda_t+Q_{344}\lambda_f+Q_{232}h=c_{l,d} \qquad (6d)$$

where λ_l is the land price (rent), p is food price and u_e is the energy cost containing

This function is a "bit" function on a land market which depends on technology "h". It can be equated with the bit function for land of the smallholder sector (next chapter). The interaction will be discussed later.

As another comment: So far the modelling has dealt with an open system with energy off-limits. This may be true, from a system perspective, that other limits in energy availability prevail. Notable if exogenous energy becomes scarce, we can take the system standpoint and ask what happens to economies of scale if energy is limited. The equations (6) represent how production and the "economic" of shadow prices are linked. The aim in the sector economics (farm sector) is to minimize shadow prices (maximize gains from production), so that production technologies impact on (increasing) shadow prices. Again we see the importance of technology choice.

3.2. Small Farm Responses

For the small scale sector, the concept is that paying subsidies shall encourage the use of organic matter, encourage energy saving (ev. carbon sequestration), and to promote recycling of soil nutrients. (In principle the model, for example, could also portray animal traction if this would be a subsidize activity, but we look at labour). A self-procurement of inputs at a minimum of fossil energy saves energy, but requires labouring for recycling. For a system oriented approach labour demand has to be specified explicitly and it is a derivative to its shadow price.

For instance, taking the derivate of (5) to the shadow price of land, the constraint becomes a different meaning as variable of land demand:

$$\delta P(q,r,\lambda/\delta\lambda_l = Q_{21}[q,r] +Q_{31}[\lambda_s,\lambda_n, \lambda_f] = c^{d}_{l} \qquad (8a)$$

In particular the land demand is of importance since it shows land use categories between small and large scale, and it enables a policy approach based on it (depicted next). The endogenous variables of food supply and recycling are obtained as derivatives (not shown) and as a solution of a simultaneous equation system we get, as before mentioned, a "demand" function for land, which is now driven by the subsidy and gross margins:

For the modelling of response functions it is sufficient to know the coefficients in (8), for instance, from a similar Maximum Entropy (ME: Paris and Howitt, 2000) analysis as suggested above. Also in a similar way (8b) we can determine recycling response to subsidies as "supply" function. To get them we take the derivatives of recycling depending on shadow prices.

$$\delta P(q,r,\lambda)/\delta r = [c\text{-}s] - Q_1[q,r] + Q_2[\lambda_s,\lambda_n,\lambda_f] = 0 \qquad (8b)$$

The illustrated structure now enables us to address policy issues and measures.

4 Response Functions for policy

Following the above outline and thinking about policy influence on response functions, we can now use the response function of the large and small scale farm sectors to establish instruments to address carbon balances and design policies to target emission. In its simplest case one can thing about a restriction on energy use and monetary compensation, if voluntarily participation in schemes is envisaged. The model enables such calculations. Alternatively we can assume a damage reduction function from GHG which has to be balanced (optimized) with payments to farmers. Let us think, at least, that premiums exist for saving green house gases (GHG) such as carbon facilities, payments by energy generation companies or government payments, etc. We follow this way. Then we have a price (or demand function) and can calculate the benefits for a government to interfere in farm optimization by taxing and subsidization. This will be outlined consecutively. However, a design of instruments, which addresses objectives in GHGs, has to be done along structural entities, found in addressing energy use. Structuring the issue we start with direct instruments and proceed with indirect.

4.1 Direct policy instruments

For the direct impact we hypothesize a link between "h", which was the tax basis and a new variable on energy $e_{u,r}$, which is to be established, exists. The measure in energy use or

carbon equivalents (potentially including other GHG) is on the basis of additional energy imposed by an expansion of "h": $e_l = \alpha\ h_l$. The introduction of the support variables "h" and its expansion increases the energy use. However, farmers will not automatically choose the least "h", because they have to pay taxes (see above). Note a reference is no tax which gives the maximum of preferred steps in technologies (see above). By raising the tax, fossil energy should use declines. Since we want to have a change from an existing situation, a first step is to do the calculation of a reference with zero or almost zero tax on the intensive technologies.

Note we further want to exhibit a sub-sector approach. It means we have a sum of farms, which differently applies economies of scale (the approach becomes a sector or regional approach). Though farms are classified in large and small farms, within the sub-sector farm sizes and economies of scale differ. As the variable "h" is a variable for farms, it means that sum of "h"s can stand for the sector. Then for policy there are two options, either (1) a direct taxing which means that farmers who use large scale equipments have to pay if they use a certain technology or (2) we foresee an indirect "t" taxing which means those who offer the technology (companies like Renault, Case, etc.) are paying and farmers are confronted with higher technology prices.

Coming back to theory: a change in the energy use, as been identified by a change in technology, used, works along: $e_{l,r} := \Delta e_l = \alpha_l\ \Delta h_l = \alpha_l[h_{l,n} - h_{l,o}]$. Then we can insert for "$h_{l,n}$" and the tax function, which we derived from the sector modelling, gives response. Parallel, for the design of an individually and directly imposed policy instruments for the small scale sector as suggested for the large scale subsector, suggestions for the small-scale sub-sector of policy instruments are subsidies on recycling, itself or labour in recycling, respectively. The question emerges how to treat the positive externalities of this sub-sector most directly. As an argument for subsidizing recycling shall be the energy saving which can be obtained as: $e_{s,r} := \Delta e_r = \alpha_s \Delta r_s = \alpha_s[r_s - r_{s,o}]$. Subsidies will increase the competitiveness of labour in recycling. Note, if we define small scale farming without economies of scale, labour subsidies would be a most convenient way, especially when recycling is not a directly observable activity. Moreover and eventually because of political reasons this is a preferred instrument. A question is, can it be only justified if we compare it with labour returns in capital/energy intensive farming? The effect of sub-sector policies adds up but we will see also joint (indirect) effects.

4.2 Structural Policy (indirect)

Here we hypothesize that the structural policy (i.e. indirect) effect of sub-sector policy instruments (tax for large scale and subsidy for small scale) could be even more important than direct ones. There should be a strong impact on the farm sub-sector composition, i.e. the land basis for less energy consuming farms (small-scale farms) is expanded to the expense of large, energy intensive farms. Increasing (maintaining, reducing migration) of the number of small farms, which per se is assumed to be less energy consuming, eventually, is a better policy than just a policy of directed energy consumption towards less energy consumption on existing farms. Note we refer for the standard argument that labour replaces energy and vice versa in sectors. But we will and aim also at structural changes on the land market.

From a re-specification of production economics and decision making towards land demand we get from the response function analysis above:

$$\lambda_{e,l} = Q\text{-}*_{32}\ A\ l_l + Q*_{32}\, c_{l,\,-l} + Q*_{33}\, c_{e,l} + Q*_{34}\, c_{t,l} \qquad (8a)$$

$$\lambda_{e,s} = Q\text{-}*_{32}\ A\ l_s + Q*_{32}\, c_{1,\,-s} + Q*_{33}\, c_{e,s} + Q*_{34}\, c_{t,s} \qquad (8b)$$

These inverse land demand functions can be equated for shadow prices and quantity ($c_{t,}+c_{t,l} = c_t$: i.e. land is limited and we receive an equilibrium on the land market as dependent on taxes and subsidies). Seeing shadow prices of land as rents, the farm structure can be determined applying energy use criteria. Technologies, output prices and constraints determine the rent. We have to think about combining policy instruments to boost less energy intensive farms.

5 Application for Policy and Objectives of Government

The response functions which have been designed for the two sub-sectors in agriculture (energy intensive highly mechanized farming and small-scale, recycling farming) are to be put into a policy perspective. For this we need an objective function. As a way to specify the objective and the constrained behavioural functions of the government we can use a concept which is similar to those of a principal and agents (Richter and Furutobn, 1996); whereby we consider the farm sectors as agents which are reflected by the behavioural functions. The instrument variables prevailing are the subsidy “s” and the tax “t” which are impacting on “h” and “l”. Furthermore, we have to clarify on the objective of the principal, the government. A simple version of a principal is that he wants to maximize the net effects of reduction of energy use (mirroring the GHG emission) minus a given amount of money available; or he minimize the money spend for energy use reduction assuming a given target of carbon emission. In our case, we prefer a depiction of an economic cost benefit analysis to find

shadow prices. We assume that a target of reduction "e_t" is associated with a benefit of a society (a demand or willingness to pay exists). One can derive this benefit form a willingness to pay analysis which is based on alternative modes to save carbon. If a linear expression of the willingness to pay is obtained, the corresponding objective function (integral) is a quadratic function (9). The objective is supposed to be achieved by the several instruments.

As said we work on a conceptual level. So far we achieved the production and recycling activities as to be associated with the emission. The overall target shall be a change in the savings in costs of carbon emission (measure in fossil energy use equivalents) given as an un-weighted function of reduction ($e_t = e_{l,r} + e_{s,r} + e_{u,r}$). We suggest a quadratic exposure which shall have a feature like in equation (9). In principle it means there is a marginal value of a demand function for reduction: alternatively on can work also with fixed prices:

$$E_r = \zeta_0 [e_{l,r} + e_{s,r} + e_{u,r}] + 0.5[e_{l,r} + e_{s,r} + e_{u,r}]' \zeta_1 [e_{l,r} + e_{s,r} + e_{u,r}] + t'h - s'r \qquad (9)$$

where: $e_{l,r}$: energy saved by land redistribution (increase land share of small farms: indirect)
$e_{s,r}$: energy saved by small farms through recycling based on subsidies (direct on farm)
$e_{u,r}$: energy saved by large farms through taxing of economies of scale (direct on farm)

Equation (9) can be modified in terms of a matrix represenation of the tax

$$E_r = \zeta_0 [e_{l,r} + e_{s,r} + e_{u,r}] + 0.5[e_{l,r} + e_{s,r} + e_{u,r}]' \zeta_1 [e_{l,r} + e_{s,r} + e_{u,r}] + [t,s]'I [h,r] \qquad (9')$$

where: I : unit matrix including -1 for the tax segment.

The instruments (tax and subsidy) in equation (9) are free choice variables and not connected to a budget. Alternatively one can combine them to a budget constraint (see below in equation 12). For the above response analysis (chapter 3 and 4) one can calculate linear relationships: $q_i = A_i e_i$; and it becomes evident that the emissions are a function of the instrument variables. Then, plus the response functions as constraints, which are the agents behavioural functions and which are outlined activities of economies of scale and recycling as well as taxes and subsidies, equations (9a to 9c) are summarized presentations of emissions.

$$A_{l,e}\, e_{l,r} = b_{l,e} + B_{l,e} [t,s]' \Leftrightarrow e_{l,r} = A_{l,e}^{-1} [b_{l,e} + B_{l,e} [t,s]'] \qquad (9a)$$

$$A_{s,e}\, e_{s,r} = b_{s,e} + B_{s,e} [t,s]' \Leftrightarrow e_{s,r} = A_{s,e}^{-1} [b_{s,e} + B_{s,e} [t,s]'] \qquad (9b)$$

$$A_{u,e}\, e_{u,r} = b_{u,e} + B_{u,e} [t,s]' \Leftrightarrow e_{u,r} = A_{u,e}^{-1} [b_{u,e} + B_{u,e} [t,s]'] \qquad (9c)$$

And we have the technology choices (9d) which are dependent straight on instruments

$$A_r[h,r]' = b_{r,0} + B_r[t,s]' \Leftrightarrow [h,r]' = A_r^{-1} [b_{r,0} + B_r [t,s]'] \qquad (9d)$$

where: A, B and b are matrices that give behavioural equations

This fourth constraint explains the relationship between the switch of technology activities on the one side (being taxed) and the recycling activities on the other side (being subsidized). Equation (9c) specifically recognizes the effects of land distribution between the two sectors.

Inserting of constraints (9a to 9d) in (9) gives an objective functions for emission reduction which depends on subsidies and taxes as policy instruments "s" and "t", only. Finally this objective can be maximized along t and s which are obtained as a result of modelling the sector:

$$E_r = \zeta_0' A_e^{-1}[b_e+B_e[t,s]'] + .5[b_e+B_e[t,s]']' A_e^{-1}{}' \zeta_1 A_e^{-1}[b_e+B_e[t,s]'] + [t,s]' \, I \, A_r^{-1} \, [b_r+B_r[t,s]'] \quad (10)$$

As this system can be solved for the taxes "t" and subsidies "s", taking the first derivative, a result is an optimal policy design (equation 11):

$$\delta E(\ldots)/\delta[t,s] = \zeta_0 A_e^{-1}{}' B_e' + A_e^{-1} \zeta_1 A_e^{-1}{}' [b_e+B_e[t,s] + I \, A_r^{-1}{}' [b_r+B_r[t,s]] = 0 \quad (11)$$

From equation (11) "t" and "s" can be calculated by matrix inversion.

Alternatively we could impose a budget constraint, if the exercise shall be financially neutral.

$$E_r = \zeta_0' A_e^{-1}[b_e+B_e[t,s]'] + .5[b_e+B_e[t,s]']' A_e^{-1}{}' \zeta_1 A_e^{-1}[b_e+B_e[t,s]'] + \lambda[z-[t,s]' \, I \, A_r^{-1} \, [b_r+B_r[t,s]']]] \quad (12)$$

where: z: budget in case of financial neutrality z is equal to zero

In this case two equation (as the derivatives to the vector of policy instruments t and s as well as λ) would give us the equation system (13):

$$\delta E(\ldots)/\delta[t,s] = \zeta_0 A_e^{-1}{}' B_e' + A_e^{-1} \zeta_1 A_e^{-1}{}' [b_e+B_e[t,s] + I \, A_r^{-1}{}' [b_r+B_r[t,s]] \, \lambda = 0 \quad (13a)$$

$$\delta E(\ldots)/\delta \lambda = z-[t,s]' \, I \, A_r^{-1} \, [b_r+B_r[t,s]'] \quad (13b)$$

The problem in (13) is that a non-linear system appears and we need linear approximations to solve it for t,s, and λ. But it is possible. Note we only sketched how a solution can be found; it is possible to accommodate (13) by a numerical analysis. The difference to the first solution is that budget neutrality prevails which means that targets of emission are the focus and money becomes neutral.

6 SUMMARY

The paper presented a modelling approach on how economies of scale in large farms and recycling in small farms can be subject to policy instruments intended to reduce carbon emission form agriculture. Different types of approaches were outlined separately and it was indicated how land demand of each sub-sector can be used to couple the sector approaches. For the individual segment of large farms we introduced a tax on energy use based on technology switches. The tax is collected according to economies of scale as discrete switches in technologies, obtainable from a linear programming background. For small farms we suggested a subsidy on recycling. This implied that recycling becomes an implemented activity in farm modelling. The tax can be used to finance the subsidy. Since economies of scale are realized by technology jumps and these jumps describe shifts to energy intensive practices, a new behavioural concept had been applied which explicitly looked for switches which are associated with fossil energy use increases. In the modelling of policy we addressed direct and indirect effects of taxes and subsidies. With regard to direct effects the tax shall impact on technology choices and the subsidy shall promote recycling which was shown. As indirect effect, with regard to the competiveness, the tax and subsidy will change land occupation as structural variable. Finally it is indicated how tax and subsidy can be optimized using an objective function of carbon costs.

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