111 EAAE-IAAE Seminar 'Small Farms: decline or persistence'

University of Kent, Canterbury, UK

26th-27th June 2009

Size, Energy Use and Economies of Scale: Modeling of Policy Instruments to Address Small Farms' Advantages if Energy Is Scarcer and Ecology Matters?

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Abstract

This paper contributes to the discussion on appropriate farm sizes as dependent on energy use and green house gas emission. Normally large farms use more energy than small farms and obtain higher labor productivity which is one of the reasons for their superiority. We presume energy includes a component of negative externality if fossil energy is used and carbon CO_2 are counted. Moreover it can be intended to use farming for carbon sequestration. In the paper we will analyze, how a new pathway can be developed, that includes incentives (taxes and subsidies) to save energy and develop coexistence between large and small farms. In favoring small scale farming because of less emission, a contribution to global warming reduction is envisaged. The issue is how can we address farm size, make incentives visible, help to switch technologies and promote farmers who adopt CO_2 saving technologies? The paper suggests a framework of linear programming and quadratic expositions of farm behavior to depict policy for optimal farm operation size and farm structures composed of large and small scale farms. A moderate position is taken with respect to sustainable farming and the question of farm size and energy use is given to policy instruments.

Keywords: Energy use, farm size and agricultural policy

1 INTRODUCTION

There is a growing discussion about current agricultural practices and its sustainability and hence a request for more sustainable agriculture (Fish et al., 2008). A major problem of current agricultural practices is that agriculture is already a major contributor to green house gas emissions, emerging from the use of fossil energy. Instead of being a carbon sink (Murray, 2004) it seems that agriculture even contributes to carbon emissions. Over the last decades, agriculture has become energy and capital intensive especially in developed western countries (Pimentel, 1980, incl. capital as congealed energy and use of fossil energy as main source of power instead of energy produced with in the sector) and labor intensive and recycling activities are diminishing, especially with structural changes towards large scale mechanized farms. Hereby agriculture increased its labor productivity and assured the survival and income of those farmers staying in business (Shankar, et al. 2003). In contrast small farms which are emitting less carbon and green house gases, at least if they are traditionally labor intensive, have become less competitive and are compelled to migrate to other sectors as a result. With respect to economic viability of farming, it seems to be an unquestionable fact that, due to economies of scale, the rule “grow or perish” (i.e. become bigger) dictates the ongoing structural change. In this light, especially for “backward” areas, the future of small scale farming does not look bright. The process of retreat even speeds up, if labor costs increase which is the case in many countries that are at the threshold of copying pathways of agricultural development of modern western countries.

However, since energy use has become an issue, large-scale, capital intensive farming is increasingly facing the challenge of being identified as unsustainable because of its contribution to CO_2. This raises the question, is there is a link between the observable variables of farm size, farming type (peasant or commercial farmer), farming system, energy use and carbon dioxide emission. A question at hand is what are suitable energy price levels and technology scopes for intensification underlying as drivers of farming structure? And how can we portray this link by modeling a policy intervention? Also the ecological-economics literature is questioning the advantage of large farms. Literature based on Georgescu-Roegen’s hypothesis (Matinez-Alier 1997) of “peasant farming as being advantageous for sustainable farming” says: yes, there is an ecological advantage for small farms, because small farms are normally more labor intensive and energy efficient than large mechanized farms. The questions which come up are what happens if energy prices increase (positive analysis) and which policy instruments can implemented which mitigate carbon dioxide reduction from the perspective of farm size (normative analysis)?

Emissions from agriculture and its carbon balances have become an issue in the discussion about sustainability because expectations are that a positive balance should exist (Lal, 2004). To put things in reference: it simply does not make sense to identify neutrality of energy and carbon as wells as some time also nutrient balances in agriculture; rather farming should be “value creating” in terms of energy generation or storage. Due to the immense importance of land use for global climate and natural resources, it is a natural request that agriculture should minimize negative effects (incl. again sometimes as also mentioned those of industry) and maximizes positive effects on carbon balances while producing food (mitigate climate change: Rose and McCarl, 2008). What counts is an ecological dividend. However, things are different in reality because fossil energy intensity is technology driven and technologies are associated with economies of scale. It is not only about zero tillage, etc. at farm level; rather sector aspects become involve, such as sizes of farm, overall energy intensity of modern farming, and factor combinations. For instance notice that the production of bio-fuels is eventually considered negative for green house gas (GHG balances: Searchinger et al., 2008).

Modeling should address these broader views and issues. Farmers will not be interested in the dividend unless they get compensated or being forced to use less fossil energy; for them the economic dividend of larger farms counts: large tractors, combine harvesters, pesticides, artificial fertilizer etc., all based on fossil energy. In such case, normally, an economist would suggest a tax on fossil energy; the tax could eventually decrease the over-proportionality within the size of farm operation based on fossil energy use measures; but we doubt and thing a technology tax is more appropriate. But there is also the option to subsidize small farms. We will contribute to the discussion by relating fossil energy use to the farm technologies, size and farmers' objective which may be different for peasants (small farmers) and large farmers.

Specifically, we want to analyze the question whether farming technologies can be less energy intensive and how this relates to capital-labor intensity ratios and farm size. If size has an impact on intensity (for low intensity is desired), what can reduce size and make small scale farming survive or acceptable to the community? As farm technologies currently suggest, low choices of substitution between energy consuming large-scale technologies and labor intensive small scale technologies seem to exist; it further seems that there are no alternatives for farmers to using heavy machinery. Farmers are not willing to reduce labor productivity for good reasons; the high labor productivity is a guarantee for high income and survival on land markets! An example is mechanized weeding instead of hand or small tool weeding. The economic environment of the last decades and corresponding technology choices have shown a co-evolution that has brought up a highly mechanized agriculture, preferably at large scale (Saifi and Drake, 2008). The immediate question is how to model the aspect of size and declining average costs in the case of scale economies and to decipher more appropriate technologies? Our approach draws on the concept of a specific linear programming of scale economy and positive quadratic programming with a reference to maximum entropy (Paris and Howitt, 1998). The characteristic aspect of economies of scale and different technologies is that average cost curves intersect and that optimal sizes of operation are discrete. This shall be depicted. The outline will follow such given structure. As alternative we hint at medium sized technologies. In a range of technologies, gaps will eventually be identified and it will be shown, whether these gaps have scope to become appropriate technologies. To do so we integrate economies of scale with ecological aspect with reference to different technologies and specify optimal policies to achieve reduction targets in GHG emissions of agriculture.

2 PROBLEM STATEMENT

As said, with respect to economic viability of farming as a business, it seems to be an unquestionable fact that due to economies of scale the rule "grow or perish" dictates large scale farming of for those who are still small to convert as quick as possible. But, in the opinion of the author it is not sufficient to prove that economies of scale exist, which justify a certain level of "necessary" fossil energy input in agriculture. Rather it is necessary to find a trigger that enables a reduction in energy. A reduction in energy use should be linked to more substitution options in the current basket of technologies and has to enable energy savings at reasonable costs. In addition, it does not seem to be realistic to request to reduce energy use and to depart from intensive agriculture, directly, if it is not conducive for farmers. For instance, western European farmers have enjoyed high labor productivity and observed the advantage of highly mechanized agriculture; they may not go back to direct laboring. Seeing small farm ecologically beneficiary, by simple logic, one would expect that it is necessary to encourage large operations to become smaller. A policy instrument to achieve an alternative farming structure, that we suggest, is a combination of a tax on the technology and capital investment in intensive farming and labor subsidy for small farms. The focus on investments is justified twofold. (1) We will discuss how the invested capital (energy) of a farm which includes negative externalities can be reduced in food production. (2) We discuss how human labor, by substituting external energy, is conducive for sustainable food production.

The paper provides policy oriented tools to identify optimal sizes of farm operations along ecological concerns, which is more closely linked to the ecological impact of farming. To do so, we integrate ecology concerns as a reference to different technologies requiring different levels of labor. In this framework, taxing and subsidizing 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. Hence a moderate position is taken with respect to sustainable farming. Subsidies will be given to laboring in small farms for recycling.

3 FARM TECHNOLOGIES AND ECONOMIES OF SCALE

Technology choices are strongly related to farm planning and can be depicted by its planning methods. However, economies of scale are rarely addressed, though Köhne has suggested a structure to deal with economies of scale quite early (Köhne, 1965). Farm modernization, mechanization and economics of scale were and are based on the use of external energy for machinery and as this machinery became ever bigger and bigger, its adoption enforced specialization and up-scaling of farm size to achieve decreasing unit-costs. Basically farmers decide on considerable investments in (advanced) technologies which give lower average costs than small-scale farming. Labor productivity has been strongly increased; notably labor shortage and costs played also a role in this cycle. With modern technologies nowadays large-scale farming is quite pervasive and it can easily out-compete small-scale farming.

Taking the energy consumption of farming as a reference for sustainability, however, as been said, huge machinery is confronted with high energy inputs and initial costs; notably in construction and using of the machinery energy is present. As a reference we also have to consider that the level of output is normally increasing with modern farming. It seems that only the current high output agriculture serves the need of a society where labor is short and farm labor has been reduced to a minimum. Notably all this depends on chosen technologies.

If energy prices increase (see 2008), however, economic viability of current farm technologies can come under threat. Given the technologies and new input prices as well as the output prices, a new constellation of average costs may lead to new demand constellations and shifts in sales opportunities. In such a scenario, the question is whether new sets of factor combinations can be realized which open up new opportunities for small farms, normally exposed to more laboring than large farms. The issue is how environmentally more conducive laboring can be reintroduced into agriculture? Can labor get better integrated into an economic description, yielding a more competitive position for small farms? Methodologically, to answer these questions, we can use mathematical programming by integrating constraints imposed on the system. Constraints imposed on sets of technologies create shadow prices, for instance, measured as opportunity costs. Shadow prices display the loss in competitiveness in terms of average cost increase; costs which would have been alternatively possible without a constraint as a reference. Such thing can be implemented for energy and labor. Additionally we can portrait a situation where a reduced use of economies of scale brings about a new national price situation for farm products. This situation, however, has to be seen in the context of international competitiveness of farming; or alternatively expressed as a problem to create instruments, being environmentally motivated and accepted (green box), i.e. accepted in WTO rounds.

Moreover, framing situations conducive to promote labor oriented small farm technologies in food business is faced with economies of scale and reasons for persistence of small farm that prevail in specific regions, such as disadvantage areas. However, questions bring in site specific issues. Some areas still have a higher potential to be less energy intensive than others as site, also because of lower requests of payments or returns for labor. Specific priorities in technologies exist, for instance for mountains and less fertile areas. Mountainous regions, so far, have still major elements of labor oriented farming, whereas favorable flatlands are mostly the forerunners of mechanization. A critical role plays animal production. It seems that different farm orientations have different intensity, apparently, also due to technology innovation priority. A further topic is the willingness of the public to redirect agriculture and get involved in income needs of farmers. We want to answer these questions by a modification of programming methods.

4 METHODS

Linear programming offers a tool to deal with economies of scale by using a sequential programming. We first present this tool and then further discuss it in conjunction with the problem of energy efficiency. However, to keep the subject operational the approach follows well-known rules of linear programming which means most problems are to be kept linear.

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	20	≥	1				
II cows	0	≥	-1	20			
III cows	0	≥		-20	1		
IV cows	0	≥			-1	20	
V cows	0	≥				-20	1

H_1 and H_2 are integer variables.

Source: Steinhäuser et al., 1992

In Figure 1, a case is outlined where we distinguish between cow production 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 (the sixties, today it maybe 200 cows which can be dealt with at the family level). The production system can not be ultimately chosen. 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 lower costs (gross margins) are conducted. Auxiliary activities are used. We are approximating a typical economy of scale function; whereas it depends on the skills of the investigator to linearize most appropriately.

Note the farm will not choose automatically the least cost activity in terms of economies of scale. Rather other constraints will determine the size of operation. As a consequence we can model small and large farms. The farms differently use external energy (see next). Additionally we can use observations from farm behavior. Farmers optimizing along the above tableau do not care about energy aspects. But, embedded energy levels are different with technologies. For the sake of empirical analysis it is important to contrast farms who have chosen strong investments and who did not. At the same time we need a generalization. A possibility is to take a model with a generalized technology and parameterize it for different farms. A question at stake is how a diminishing curve of economies of scale can correctly represent technologies. Normally there is an overlapping of technologies or even missing technologies. It can be presumed that under cheap energy scenario, large-scale farm technologies, as mechanized (i.e. with congealed energy) farming, dominate. For instance, current technology evolution has had a focus on diminishing unit-costs. In a dynamic competition favoring increased scale, it is difficult to specify medium scale technologies. In this case a reconstruction of older technologies may help to establish a spectrum of energy use, capital and farm size.

5 ENERGY CONSTRAINTS AND LARGE FARMS

Using the scheme of programming above, the aspect of energy use has to be re-integrated into programming. An easy way is to integrate a restriction on energy use or carbon dioxide emission. A more complicated way would be to reconsider also ecologies of scale. Since the programming contains the discrete acquisition of equipment we can calculate the embodied energy in the equipment, either. To confront programming and the choice of technologies with prevalent economies of scale it has to clarified, how the actual status of investment is linked to carbon emission. For instance, the size of a tractor, i.e. one large tractor or combine harvester on a farm is the result of decisions that should be emulated by the programming, so it is an individual activity. In other cases we have mixed combinations of technologies; these mixes are to be counted. Essentially small farms are more likely to have a mixed combination.

Then we enter into the sphere of energy needs and potential energy use constraints. A question is how do we deal with energy as input? Moreover the approach should be closely linked to CO_2. It is assumed that external fossil energy use of agriculture is directly linked to CO_2 emission. For a first approach it is stated that farmers get a quota of emission rights, i.e. a quota of energy embodied in machinery and running and allocating them if they want to produce along economies of scale. Then the question expands along different types of machinery, farm equipment and measures that constitute modern energy intensive farming. The energy use can be calculated in diesel equivalents or/and kilowatt hours. From the previous economies of scale analysis, suggested in the linear programming frame, we resume internal categories or steps of the choices on technologies and emission. They prevail as constraints in the technology matrix. We include this as a constraint c_t. 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.

$$\text{Max } \{ [p-u]' q \;\; - t'h\} \qquad (1)$$
$$A_{11}\, q < c_1$$
$$A_{12}\, q < c_l$$
$$A_{13}\, q - Z_{11}\, h < c_e$$
$$Z_{11}\, q - Z_{12}\, h < b_e$$

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

This formulation includes the potential steps for the economies of scale as a variable "h". Furthermore steps are optional on taxes. In the classical model steps are without costs; they serve purely as additional variable form a technical point of view to enter into new unit cost depreciations as been subject to large investments. Taxes 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 steps is possible by accepting different tax levels.

Two aspects are involved as a tax on technologies is imposed: (1) Technology choices are redirected and (2) competitiveness on the land market is changing. A tax reduces profits residual but also impedes decreases in costs. 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 for the outline:

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

where $\lambda_{1,t,e,s}$: shadow prices

Note that our farm model works with an imposed energy constraint. The optimized farm activities and shadow prices for traditional constraints are internally derived. The additionally imposed energy constraint is also a part of analysis where energy (CO_2) concerns are expressed in constraints. The consequence is that costs of production are rising for those farming systems which are strongly fossil energy based. Up to a certain point, however, this only reduces the competitiveness; it does not impact on absolute profitability. But output price can be eventually affected. In such context, an analysis on the system-wide implications is needed. System-wide implications means that impacts on prices, i.e. the possible change in price levels, as an impact of the reduced possibility to use external energy, is studied. A reference to energy pricing is needed. In our analysis we assumed low energy prices and can portray inelastic responses to energy cost increases. This happens because technologies are inflexible. In traditional approaches the analysis offers a willingness to pay for energy if a constraint is imposed. This is not the equilibrium case. The reader might think how ecological concerns can be better expressed than just imposed as constraints.

A next step is to translate the programming results into functions. For the moment we only sketch a procedure how to retrieve flexible functional forms. The method uses positive mathematical programming. As result one can obtain a quadratic cost function (Paris & Howitt [6]):

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

Some remarks are necessary concerning observation on technologies and modeling with steps (constraints). (1) As been outlined by Howitt and Paris [6], the flexible form of quadratic modeling allows a delivering of marginal values. (2) A divergence between observations and internally calculated shadow prices or unit cost, respectively, is possible and the limitations of linear programming with respect to non-equal conditions can be overcome. Technically, the same can be applied to steps in economics of scale and some steps actually must not be fully met; rather for the empirical foundation we have to seek to include additional observations on technology choice (i.e. to distinguish those step met and those not in economies of scale, by setting some balances to nil and looking for several farmers we can obtain a sector function). For those observations on technology (for example on the size of tractor which is 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 big machinery) which are met, equality balances can be re-introduced (otherwise not). Note "h" is a variable changing steps. This enables a better representation of the equation that counts for the tax implementation. Taxes are not uniform based on energy equivalent; rather they are progressive. Tax functions become smooth 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.

6 APPLICATION FOR POLICY

The working idea is that a quasi demand function for energy and carbon dioxide, respectively, can be derived. This function shall be dependent on taxing of technologies and we want to link it to farm sizes. Shadow prices give demand functions [6]. They are the first derivatives of the profit function. Further note that the linear "technologies" still matter, i.e.: $A_{11}\ q = c_l$ 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 can vary for agronomy criteria [9]), 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 (3b) depicts the constraint (demand) as shadow price function for land. Various constraints (for energy (3a), etc.) are "explained" by the derivative of the "cost" function from (3) which gives the following outline:

$$\delta P(q,h,\lambda_s,\lambda_e,\lambda_t,\lambda_f)/\delta\lambda_e=Q_{221}q+Q_{321}\lambda_s+Q_{322}\lambda_e+Q_{323}\lambda_t+Q_{324}\lambda_f+Q_{212}h=c_e \quad (3a)$$

Then also:

$$\delta P(q,h,\lambda_s,\lambda_e,\lambda_t,\lambda_f)/\delta\lambda_l= Q_{211}q+Q_{311}\lambda_s+Q_{312}\lambda_e+Q_{313}\lambda_t+Q_{314}\lambda_f+Q_{222}h=c_l \quad (3b)$$

$$\delta P(q,h,\lambda_s,\lambda_e,\lambda_t,\lambda_f)/\delta\lambda_f= Q_{231}q+Q_{331}\lambda_s+Q_{332}\lambda_e+Q_{333}\lambda_t+Q_{334}\lambda_f+Q_{232}h=c_f \quad (3c)$$

…

The inversion of the matrices delivers a behavioral equation such as.

$$\lambda_e = Q_{31}\ q + Q^*_{32}\ c_1+ Q^*_{33}\ c_e+ Q^*_{34}\ c_t + Q^*_{34}\ c_t + Q^*_{35}\ b_e + Q^*_{45}\ h \quad (4a)$$

Firstly, from (4a) a shadow price for energy constraints can be calculated. Secondly it shows how this value depends on the choices q and h. Furthermore, the profit can be optimized to q and h and finally this will create a relationship between prices (or gross margins respectively), including taxes and constraints on the technologies.

$$\lambda_e = Q^{**}_{31}\ [p-c] + Q^{**}_{31}\ t + Q^{**}_{32}\ c_1+ Q^{**}_{33}\ c_e+ Q^{**}_{34}\ c_t+ Q^*_{35}\ b_e \quad (4b)$$

For a later policy analysis we can show that the tax can be translated into prices of farm energy if this energy should come alternatively from internal sources of the farm sector. The same can be done for farm labor, land, etc. We can further work with such specification of derived shadow prices as constraint in ecological modeling. The interesting aspect is that the separate optimizations provide necessary conditions to be met in a second layer of sector optimization of energy use as shared between small and large farms. The second layer corresponds to incentive constraints like in principal agent approaches [10]. Our first layer optimization characterizes the behavior of farmers with respect to existing or imposed energy constraints and taxes. The availability of energy for individual farms may be not constraining; rather farmers presume that energy is purchased from market, but the government can introduce environmental budget on green house gases. We can take the energy price or the shadow price as calculations for the change in profitability. If we take the constraint it offers a change to depict the energy demand of the farms. A similar opportunity 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:

$$Q^{l}_{21}[p-u_e]+Q_{341}\lambda_s+Q_{342}\lambda_e+Q_{343}\lambda_t+Q_{344}\lambda_f+Q_{232}h=c_{l,d} \quad (3d)$$

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

This function is a "bit" function on a land market. It can be equated with the bit function for land of the smallholder sector. This will be discussed later.

So far the modeling has dealt with an open system with energy limits. It 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 (3) represent how production and "economic" shadow prices are linked. The aim in (farm) economics is to minimize shadow prices (maximize gains from production), so that production technology is impacting on (increasing) shadow prices. Again we see the importance of technology choice.

7 GENERALIZED FARM ECONOMICS OF SMALL FARMS

In principle and at least in an analogous procedure, but now for a small scale farms, programming gives us a similar outlay of response functions as in the large-scale case. Though note that there is a major difference in the design of the programming. For the small scale sector we presume that farmers are recycling organics, devoting labor to it, and that no economies of scale prevail, rather labor intensive technologies are prevailing. Especially, recycling is a costly internal activity in terms of labor requirements which delivers soil nutrients from animal wastes, crop residues, etc.; i.e. we are looking at mix farms. It means that from a competiveness point of view, recycled nutrients are more expensive than their purchased counterparts, i.e. if we would take the wage or labor productivity of large farms as reference, respectively. The recycling as a labor requesting activity can be introduced as an internal activity delivering nutrients from harvested organic matter and as substituting mineral fertilizer. Nutrients do not have financial costs, per se, meaning that no value appears in the objective function, but opportunity costs. As a costly activity, recycling negatively contributes to the farm objective by binding labor, but expenses for mineral fertilizer are saved. Assuming labor surplus it may work, but at low returns and with poor farmers who work hard because they can not afford mineral fertilizer and machines. Eventually, only if we assume that a government can subsidize small farms, activities of recycling pay. Note that recycling means less fossil energy use, for instance for nitrogen fertilizer, etc. A similar programming approach (5) on optimization of smallholders, now with recycling is a first steps to achieve

$$\text{Max } \{ [p-u]' q - [u-s]'r\} \quad (5)$$
$$A_{11}\, q + A_{21}\, r < c_l$$
$$A_{12}\, q + A_{21}\, r < c_t$$
$$A_{13}\, q - A_{23}\, r < n_r$$

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 behavioral functions (6). For re-formulation, as a flexible function which can accommodate policy instruments, we get, as indicated above in the same vein of positive quadratic programming but now for small scale technologies, a functional representation of a profit function. This profit function (6) takes into account subsidies and gives values for the constraints as shadow prices.

$$P(q,r,\lambda)=[p-c]'q-[c-s]'r-.5[q,r]'Q_1[q,r]+[q,r]'Q_2[\lambda_s,\lambda_n,\lambda_f]+.5[\lambda_s,\lambda_n,\lambda_f]'Q_3[\lambda_s,\lambda_n,\lambda_f] \quad (6)$$

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. The concept is that subsidy payments encourage the use of organic matter and recycled soil nutrients. (In principle the model could also portray animal traction). A self-procurement of inputs at a minimum of fossil energy saves energy, but requires laboring for recycling. For a more system oriented approach labor demand has to be specified explicitly and it is a derivative to its shadow price. The constraint becomes a different meaning as variable:

$$\delta P(q,r,\lambda/\delta\lambda_l = Q_{21}[q,r] + Q_{31}[\lambda_s,\lambda_n, \lambda_f] = c^d_l \quad (7a)$$

For the modeling it is sufficient to know the coefficients, for instance from a similar Maximum Entropy (ME) analysis as suggested above. Also in a similar way we can obtain a land demand and a recycling or “supply” function. To get them we take the derivatives to the shadow prices for land:

$$\delta P(q,r,\lambda/\delta r = [c-s] - Q_1[q,r] + Q_2[\lambda_s,\lambda_n,\lambda_f] = 0 \quad (7b)$$

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. The endogenous variables of food supply and recycling are to be derived from a similar derivation (not shown) and as a solution of a simultaneous equation system we get, as before, a “demand” function for land, which is now driven by the subsidy and gross margins:

$$Q^s_{21}[p-c] + Q^s_{31}\,\lambda_{s,l} + Q^s_{32}\,p_e + Q^s_{33}\,s = c^s_{l,d} \quad (7c)$$

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

8 POLICY

For policy analyses we can use the above general outline by distinguishing between the energy of small and large scale farms and their land use. We presume that the two types have different technologies and hence are different in energy use intensity. Two questions emerge: (1) How can we achieve reduced energy consumption and hence CO_2 equivalents, respectively, in the sub-sector and (2) how can redistribution of land between farm types help to reduce carbon and other green house gas emissions? Notably the redistribution of farm types can be considered having stronger impacts on green house gas balances than direct policy.

Note, by knowing or determining analytically the land use pattern of small and large-scale farms, i.e. by describing marginal use values of land, it is possible to redirect land use in favor of less carbon and other green house gas emission technologies. However, policy recommendations go along opportunity costs of land. A redirection is an indirect mode to CO_2 reduction whereas taxing of energy use or subsidization of labor is a direct way to encourage low-energy food production. Hereby we can distinguish between structural and farm based policies.

8.1 General remarks on policy design

Following the above outline and thinking about policy design, we can use the response function of the large and small scale farm sectors to establish instruments to address carbon balances. In its simplest outline of instruments one can thing about restrictions on energy use and monetary compensation, if voluntarily participation in schemes is envisaged (along the line of principal agent modeling: Richter and Forobutn, 1997). Additionally we can assume a damage function which has to be balanced (optimized) with payments to farmers. Then farmers are agents and the government is a principal. Let us think, at least, that premiums exist for saving green house gases (GHG) such as carbon facilities, payments by energy companies or governments, etc. This will be outlined soon. However, a design of instruments which addresses objectives has to be done along structural entities found for addressing energy use. Structuring the issue we start with direct instruments and proceed with indirect.

8.2 Direct policy instruments

For the direct impact we hypothesize a link between “h”, the technology, which shall be the tax basis and a new variable on energy $e_{u,r}$, which is to be established. The measure in energy is based on additional energy imposed by an expansion of “h”: $e_l = \alpha\ h_l$. The introduction of the support variables “h” increases energy use. Now, farmers will not automatically choose lowest unit costs because they have to pay tax (see above). Note a reference is no tax which gives the maximum of preferred steps in technology (see above). By raising the tax, fossil energy use declines. Note we further want to exhibit a sector approach. It means we have a sum of farms, which differently use economies of scale. As the variable “h” is variable for farms, it means that sum of “h”s can stand for the sector. To link modeling to reality, at the sector level we get for instance, the number of tractors in size categories (0 to 15 horse power, 15 to 45 horse power, etc.). The switch between the technologies shall be taxed. 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 industry “t” taxing which means those who offer the technology (Renault, Case, etc.) are paying. Because taxes shift prices for technologies farmers may prefer more labor intensive technologies; farms get smaller. For convenience and minimizing transaction costs in tax collection the second alternative is apparently more attractive: To make things technical, a change in the energy use, as been identified by a change in technology used, works along: $e_{l,r} := \Delta e_l = \alpha_1\ \Delta h_l = \alpha_l[h_{l,n} - h_{l,o}]$. Then we can insert for $h_{l,n}$ and get the tax function which we derive from the sector modeling given responses.

Parallel to large farms, for the design of an individually and directly imposed policy instruments in the small scale sector, suggestions are to be made for subsidies on recycling and/or labor in recycling, respectively. The question emerges how to treat the positive externalities of this sector (lower emission, ev. sequestration) most directly. As an argument for subsidizing recycling we take the energy saving: $e_{s,r} := \Delta e_r = \alpha_s \Delta r_s = \alpha_s[r_s - r_{s,o}]$. Subsidization will increase the competitiveness of labor in recycling and also the production pattern will change, because labor intensive production of food becomes preferred. Furthermore we have to see technology switches presumed within farming. If we define small scale farming without economies of scale, alternatively labor subsidies would be a convenient way, especially when recycling is not a directly observable activity; and eventually because of political reasons this is a preferred instrument. But, that can be only justified if we compare it with labor returns in capital/energy intensive farming. Policy so far assumes a fixed proportion of large and small farms on land markets; however this is changeable and subject of the next consideration.

8.3 Structural Policy (indirect)

The structural policy component (as indirect) may be more important than direct ones. If there is a stronger impact on farm composition, the basis for less energy consuming farms is expanded. Increasing the number of small farms, which are 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 went for the standard argument that labor replaces energy and vice versa in sectors. Additionally the tax on large farms can finance the subsidy. We need and aim also at structural changes on the land markets. To give the argument: From a re-specification of production economics and decision making towards land demand we get:

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

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

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

8.4 Objectives of government

As a way to specify the objective function and the constrained behavioral functions of the government we can use a concept which is similar to those of a principal and agents (Richter and Forobutn, 1997); whereby we consider the farm sectors as agents which are reflected by their behavioral functions. The instrument variables prevailing are "s" and "t" impacting on "h" and "r". Furthermore, we have to clarify on the objective. A simple version of a principal would be that he wants to maximize the net effects of reduction of energy use at a given amount of money available; or he minimize the money spend for energy use reduction assuming a given target. In our case, it is an economic cost benefit analysis. We assume a target of reduction "e_t" is priced as benefits and the costs of the several instruments are deducted.

The target is a change in the saving in costs of carbon emission a sector can provide (measured in energy use equivalents) given as an un-weighted function of reduction ($e_t = e_{l,r} + e_{s,r} + e_{u,r}$). Here it shall have a quadratic feature (in principle it is a marginal value or demand function: alternatively on can work also with fixed prices):

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

where: $e_{l,r}$: energy saved by land redistribution (increase land share of small farms: indirect)
$e_{ls,r}$: 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)

Then, plus constraints (which are the agents behavioural functions as outlined above) given through the above analysis of linking energy use, activities of economies of scale and recycling as well as taxes and subsidies ere:

$$A_l[e_{l,r}+e_{s,r}+e_{u,r}]' = b_{l,0}+B_l[t,s]' \Leftrightarrow [e_{l,r}+e_{s,r}+e_{u,r}]' = A_l^{-1}\,[b_{l,0}+B_l[t,s]'] \quad (9b)$$

and

$$A_2[h,r]' = b_{l,0}+B_l[t,s]' \Leftrightarrow [h,r]' = A_2^{-1}[b_{l,0} + B_l[t,s]'] \quad (9c)$$

where: A, B and b are matrices that give behavioural equations and the instruments are in a vector

Inserting of constraints in (9a) gives a variable function (10) for reduction of energy as policy instruments:

$$E_r = \zeta_0' A_l^{-1}[b_{l,0}+B_l[t,s]']+.5[b_{l,0}+B_l[t,s]']' A_l^{-1\prime}\zeta_1 A_l^{-1}[b_{l,0}+B_l[t,s]'] - [t,s]A_2^{-1}[b_{l,0}+B_l[t,s]'] \quad (10)$$

This system can be solved for the optimal taxes "t" and subsidies "s". Also we could impose a budget constraint, if the exercise shall be financially neutral.

9 Summary

We presented a model on how economies of scale in large farms and recycling in small farms can be subject to policy instruments. We assumed diminishing returns from reduction of energy use in agriculture. For the individual segment of large farms we charge a tax on energy use base on technologies. The tax is collected according to economies of scale, obtainable. For small farms we suggested a subsidy on recycling. We deliberately introduced the tax for the switch between technologies. Since economies of scale are realized by technology jumps and these jumps describe shifts to energy intensive practices, a new behavioral concept is suggested. In the modeling of policy we addressed direct and indirect effects of taxes and subsidies. With regard to direct effects the tax will impact on technology choices and the subsidy promotes recycling. 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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