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Economies of scale, energy use and enterprise size in agriculture: modeling of policies to reduce carbon dioxide and greenhouse gas emissions

Ernst-August Nuppenau

*Department of Agricultural Policy
and Market Analysis
J.-L.University, Giessen, Germany
E-mail: Ernst-August.Nuppenau@agrar.uni-giessen.de*

Normally, large farms use more energy than small farms and obtain higher labour productivity, which is one of the reasons for their superiority. In this paper, we will analyse how to model the effects of economies of scale and technology choices and how a new pathway can be developed, that includes incentives to save energy and develop coexistence of large and small farms. The issue is how we can address farm size and energy use by taxing and subsidization to reduce carbon emission of agriculture? The paper suggests a framework of linear programming and quadratic expositions of farm behaviour to identify optimal farm operation with different concerns of small and large-scale segments for labour productivity, energy productivity and recycling. Based on energy use, it will be shown how optimization and farm structures differ. The research is targeted at Eastern European countries which face challenges of structural change and are keen to seek subsidies for sustainable agriculture within the EU.

Key words: energy use, farm size, technologies and agricultural policies

INTRODUCTION

There is a growing discussion about more sustainable agriculture (Fish, 2008). Over the last decades, agriculture has become energy and capital intensive, especially in developed western countries (Pimentale, 1980), including capital as congealed energy and the use of fossil energy as the main source of power instead of energy produced within the sector). Hereby agriculture increased its labor productivity and assured the survival and income of farmers staying in business (Shankar, 2003). 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. 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" Eastern European, small-scale farming is not the future and it does not look bright for small farms; particularly, if labour costs further increase, these farms will give up business and landscape changes. A question is whether they should follow the same pathway.

There seem to be an individual and societal problem. The ecological-economic 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. Foremost, since emissions from agriculture and its nutrient balances have become an issue, measures are sought to reduce emissions (Lal, 2004). We will contribute to the measurement debate by relating emissions to farm size and farmers' objective. The objectives may be different for peasants and farmers. We will show how policy instruments such as taxes for energy use and technologies as well as subsidies for labour can redirect the behaviour of farms and result in a farm sector emitting less CO_2 or sequester it.

The immediate question is how to model the aspect of farm size and declining average costs in case of scale economies and to decipher more appropriate technologies. For the sake of instrument and policy design, we need a model of responses to instruments and their optimization. Our approach draws on the concept of positive quadratic programming with a reference to maximum entropy (Paris, 2007). The 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 a given structure. As an alternative, we hint at medium-sized technologies. In a range of technologies, gaps will be identified, and it will be portrayed how these gaps have a scope to become appropriate technologies. To do so, we integrate economies and ecological concerns with reference to different technologies and specify optimal policies to achieve reduction targets in greenhouse gas emissions of agriculture.

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. Also, there may be ecologies of scale beyond current technologies. But, in the opinion of the author, it is not sufficient to prove that ecologies of scale exist and justify a certain level of "necessary" energy input in agriculture. Rather, it is necessary to find a trigger that enables a reduction in fossil energy use, which is correlated with the CO_2 emission of agriculture. A reduction in energy use should be linked to 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 if it is not conducive for farmers. For instance, western European farmers have enjoyed high labour productivity and observed the advantage of highly mechanized agriculture; they may not go back. It may be different in transition countries, but it remains a problem because more labour is required. Seeing small farm ecologically beneficiary (though also labour-intensive), by simple logic, one would expect that it is most appropriate to encourage large operations to become smaller. But this would not work. We need a combination of instruments that eventually favour small farms which are already using less fossil energy and look in the farm structure, i. e. help such farms to remain competitive. A policy design to achieve an alternative farming structure that we suggest is a combination of a tax on the capital investment and a waiver or tax on labour in intensive farming. The focus on scale is justified twofold: (1) we discuss how the invested capital (energy) of a farm which includes negative externalities can be reduced in the overall food production; (2) we discuss how human labour, by substituting external energy, is conducive for sustainable food production.

The paper discusses tools to identify optimal sizes of farm operations along ecological concerns which are 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 labour. In this framework, taxing will be outlined. Taxes will be differently assigned to technologies with the 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.

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. In Table, 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 that this is also an original example of Köhne (Köhne, 1965). It shows a case of milk production in which more than sixty cows were a large farm (today it may be 200 cows which can be dealt with at the family level). The production system cannot be ultimately chosen. The clue is that, in order to get the least cost activity in the programming, other activities are to be chosen before. The highest gross margin is only achieved if activities with lower costs (gross margins) are conducted. We are approximating a typical economy of scale function, whereas it depends on the skills of the investigator to linearize most appropriately. Note that the farm will not choose automatically the least cost activity

Table. **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
Labour	3600	≥	100	–5	30	0	20
Other restrictions	b2	≥			.		.
	…	…			.		.
	bm	≥		0	.	0	.
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

Source: Steinhäuser, 1992.

in terms of economies of scale. The other constraints will determine the size of operation as driven by the most binding constraint. As a consequence, we can model small and large farms. These farms differently use external energy (see below). Additionally, we can use observations from farm behaviour. Farmers optimizing along the table do not care about energy aspects. However, 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 supplement it with observations.

ENERGY CONSTRAINTS AND GENERALIZED FARM ECONOMICS FOR LARGE FARMS

Using the above scheme of programming, 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. Then we enter into the sphere of energy needs and potential energy use constraints. A question is: how do we deal with energy as an 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? Moreover the approach should be closely linked to CO_2 matters. It is assumed that external fossil energy use of agriculture is directly linked to CO_2 emission, either directly at a farm level or indirectly from energy / CO_2 involved in the production of equipment. For the first approach, it is stated that farmers get a quota of emission rights, i. e. a quota of energy embodied in machinery and running 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. From the previous economies of scale analysis, suggested in the linear programming frame, we resume internal categories or steps of the choices on technologies. They prevail as constraints in the technology matrix. We include this as a constraint c_t. Note that 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.

This formulation includes the potential steps for the economies of scale as the variable h. Furthermore, steps are optional on taxes. In the classical model, steps are without costs; they serve purely as an additional variable from the technical point of view to enter into new unit cost depreciations as subject to large investments. Taxes are later to be chosen based on the delineated response functions. 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 that 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 profit, residual, but also impedes decreases in costs. Technically, programming combines dual and primary solutions. Correspondingly, we are able to specify the dual problem of minimizing the shadow prices. Minimizing shadow prices later refer to demand functions of inputs. For the moment, the result of the optimization based on programming is given for the outline:

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

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 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 absolute profitability. But output price can be eventually affected. In such context, an analysis on the system-wide implications is needed. System-wide implications mean that impacts on prices, i. e. a 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 have 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 a result, one can obtain a quadratic cost function (Paris, 2000):

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

Some remarks are necessary concerning the observation on technologies and modeling with steps (constraints): (1) as outlined by Howitt and Paris (Paris, 2000), the flexible form of quadratic modeling allows delivering the 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 economies 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 steps 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 of land to meet the economies of scale of big machinery) which are met, equality balances can be re-introduced (otherwise not). Note that h is a variable of changing steps. This enables a better representation of the equation that counts for the tax implementation. Taxes are not uniformly 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 outlined, are part of decisions for farm size and structure.

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 size. Shadow prices give demand functions (Paris, 2000). They are the first derivatives of the profit function. Further, note that the linear "technologies" still matter, i. e. $A_{11}\, q = c_1$ and $A_{12}\, q = c_e$ represent balances. Then, by the use of derivatives and the generalization of technologies applied on representative farms which can vary by agronomy criteria (Röhm, 2003), we can offer analytical solutions for the optimization of 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 a 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:

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

Then also:

$$\begin{aligned} & \delta P\,(q, h, \lambda_s, \lambda_e, \lambda_t, \lambda_f)\, /\, \delta\, \lambda_l = Q_{211}\, q + Q_{311}\, \lambda_s + \\ & Q_{312}\, \lambda_e + Q_{313}\, \lambda_t + Q_{314}\, \lambda_f + Q_{222}\, h = c_1, \end{aligned} \tag{3b}$$

$$\begin{aligned} & \delta P\,(q, h, \lambda_s, \lambda_e, \lambda_t, \lambda_f)\, /\delta\, \lambda_f = Q_{231}\, q + Q_{331}\, \lambda_s + \\ & Q_{332}\, \lambda_e + Q_{333}\, \lambda_t + Q_{334}\, \lambda_f + \mathrm{Q}_{232}\, h = c_f\,. \end{aligned} \tag{3c}$$

...

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

$$\begin{aligned} & \lambda_e = Q_{31}\, q + Q^{*}_{32}\, c_1 + Q^{*}_{33}\, c_e + Q^{*}_{34}\, c_t + \\ & Q^{*}_{34}\, c_t + Q^{*}_{35}\, b_e + Q^{*}_{45}\, h. \end{aligned} \tag{4a}$$

Firstly, from (4a) a shadow price for energy constraints can be calculated. Secondly, it shows how this value depends on the choices of 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:

$$\begin{aligned} & \lambda_e = Q^{**}_{31}\, [p{-}c] + Q^{**}_{31} t + Q^{**}_{32} c_1 + \\ & Q^{**}_{33} c_e + Q^{**}_{34} c_t + Q^{*}_{35}\, b_e\,. \end{aligned} \tag{4b}$$

For the later policy analysis, we can show that the tax can be translated into prices of farm energy, if this energy comes alternatively from internal sources of the farm sector. The same can be done for farm labour, land, etc. We can further work with such specification of derived shadow prices as a constraint in ecological modeling. An interesting aspect is that separate optimizations provide necessary conditions to be met in the 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 (Richter, 1997). Our first layer optimization characterizes the behaviour 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 the market, but the government can introduce environmental budgets on greenhouse 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 possibility 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:

$$\begin{aligned} & Q^{l}_{21}\, [p{-}u_e] + Q_{341}\, \lambda_s + Q_{342}\, \lambda_e + Q_{343}\, \lambda_t + \\ & Q_{344}\, \lambda_f + Q_{232}\, h = c_{l,\, d}\,, \end{aligned} \tag{3d}$$

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

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

So far, the modeling has dealt with an open system with energy limits. It may be true from the 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.

GENERALIZED FARM ECONOMICS FOR SMALL FARMS

In principle and at least in an analogous procedure, but now for small-scale farms, programming gives us a similar outlay of response functions as in the large-scale case. However, note that there is a major difference in the design of the programming. For the small-scale sector, we presume that farmers recycle organics, devote labour to it, and that no economies of scale but rather labour-intensive technologies prevail. Especially, recycling is a costly internal activity in terms of labour requirements, which delivers soil nutrients from animal wastes, crop residues, etc., i. e. we are looking at mix farms. It means that from the competiveness point of view, recycled nutrients are more expensive than their purchased counterparts, i. e. we take the wage or labour productivity of large farms as a reference, respectively. Recycling as a labour-requesting activity can be introduced as an internal activity delivering nutrients from harvested organic matter and as a substituting mineral fertilizer. Nutrients do not have financial costs *per se*, meaning that no value appears in the objective function, but they have opportunity costs. As a costly activity, recycling negatively contributes to the farm objective by binding labour, but expenses for mineral fertilizers are saved. Assuming labour surplus, it may work, but at low returns and with poor farmers who work hard because they cannot afford mineral fertilizers and machines. Eventually, only if we assume that government can subsidize small farms, activities of recycling pay. Note that recycling means less fossil energy use, for instance, for nitrogen fertilizers, etc. A similar programming approach (5) to optimization of smallholders, recycling is the first steps to achieve a corresponding generalized behavioral function (6). For reformulation, 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 to the constraints as shadow prices.

$$\text{Max } \{[p-u]'\, q - [u-s]'\, r\} \qquad (5)$$
$$A_{11}\, q + A_{21}\, r < c_1$$
$$A_{12}\, q + A_{21}\, r < c_t$$
$$A_{13}\, q - A_{23}\, r < n_r,$$

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.

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

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 fertilizers. 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 labouring for recycling. For a more system-oriented approach, labour demand has to be specified explicitly, and it is a derivative to its shadow price. The constraint gets a different meaning as a variable:

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

For 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:

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

The land demand is of importance since it shows land use categories between small and large scales, 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:

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

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

RESULTS FOR POLICY DESIGN

For policy analysis, we can use the above general outline of farm sectors and their technology as well as behaviour by distinguishing between small- and large-scale farms and their land use occupation. We presume that the two types have different technologies and hence are different in energy use intensity. The idea is to shift land use in order to reach less emission. The technologies are represented by different matrices *Q*, and specifications of production alternatives are given in the above vein. Moreover, since we can specify energy use (which is an activity in the language of linear programming) individually and according to the need of energy or energy intake, a farm analysis of energy requirements can be easily accomplished.

Two questions emerge next: (1) how can we reduce energy consumption and hence CO_2 equivalents, respectively, which mirror CO_2 emission reduction efforts, particularly through addressing the farm types (in that sector)? (2) How can the redistribution of land (between sub-sectors) help to reduce carbon and other greenhouse gas emissions? Notably, the distribution of farm types (sub-sectors) can be considered to have strong impacts on greenhouse gas balances.

In general, due to the theory of substitution, we presume that energy from human labour and animal traction was strongly substituted by fossil energy in the past. But we see the potential for a reverse, limited by the large-scale sector. The term "large farm" as in this paper strongly refers to mechanized farms employing just a few labourers, whereas small farms normally are less mechanized. In the following, we address the whole farm sector having in mind the composition of the whole sector. For clarification, we exclude highly energy-intensive small farms, such as greenhouse or pig breeders. Our analysis is land-oriented, and we tackle the conflict between size increases as occurring in mechanized farms versus a limited energy fossil use of energy on small farms. Hereby, the assumption is normally that large mechanized farms out-compete small farms on the land market. As is shown in the provision of the linear programming, land was a constraint. In positive programming, land can become a demand function. Specifications of land demand functions concern not only the estimation of cost functions for farms, based on programming techniques and maximum entropy, but also land use. The advantage is that a flexible (linear) function as a demand function for land can be derived. This demand function uses shadow prices as implicit values (i. e. land rents linked to gross margins) of the two sub-sectors and equates them respectively. We combine the two demand functions, and the equilibrium on land market can be stated, which includes characteristics of energy use.

Note that by knowing or analytically determining the land use pattern of small and large-scale farm subsectors by describing marginal use values of land, it is possible to redirect land use in favour of less carbon and other greenhouse gas emission favouring the small scale sector. However, policy recommendations go along opportunity costs of land. The redirection is an indirect mode of CO_2 reduction, whereas taxation of energy use or subsidization of labour are a direct way to encourage low-energy food production. Hereby we can distinguish between structural and farm-based policies.

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 case, one can think about restriction on energy use and monetary compensation, if a voluntary participation in the schemes is envisaged. The model enables such calculations. Alternatively, we can assume a damage function which has to be balanced (optimized) with payments to farmers. Let us think, at least, that premiums exist for saving greenhouse gases (GHG) such as carbon facilities, payments by energy generation companies or government payments, etc. Then, we have a price and can calculate the benefits for a government to infer in farm optimization by taxation and subsidization. This will be outlined soon. However, a design of the instruments that address the objectives has to be done along structural entities found for addressing energy use. In structuring the issue, we start with direct instruments and proceed with indirect ones.

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. The measure in energy use and CO_2 is based on additional energy imposed by an expansion of h: $e_l = \alpha\, h_l$. The introduction of the support variables h and expansion increases the energy use. However, farmers will not automatically choose it, because they have to pay tax (see above). Note that a reference is no tax which gives the maximum of preferred steps in technology (see above). By raising the tax, fossil energy use declines. Since we want to change the existing situation, the first step is to do the calculation of the reference with a zero or almost zero tax on the intensive technologies. Note that we further want to exhibit a sub-sector approach. It means that we have a sum of farms which differently use economies of scale (the approach becomes a sector or regional approach). Though farms are classified into 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 the sum of h 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 equipment have to pay if they use a certain technology or (2) we foresee an indirect t taxation which means that those who offer the technology (Renault, Case, etc.) pay, and farmers are confronted with higher technology prices.

A change in the energy use, as identified by a change in the 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 substitute for $h_{l,n}$, and the tax function which we derived from the sector modeling gives the response.

In 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. An argument for subsidizing the recycling is the energy saving that can be obtained: $e_{s,r} = \Delta e_r = \alpha_s\, \Delta r_s = \alpha_s\, [r_s - r_{s,o}]$. This will increase the competitiveness of labour in recycling. Note that if we define small-scale farming without economies of scale, alternatively labour subsidies would be a convenient way, especially when recycling is not a directly observable activity, and eventually for political reasons this is a preferred instrument. However, that can 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.

STRUCTURAL POLICY (INDIRECT)

The structural policy (indirect) effect of sub-sector policy instruments (tax for large scale and subsidy for small scale) may be even more important than direct ones. There should be a strong impact on the farm sub-sector composition, i. e. the basis for less energy consuming farms (small-scale farms) is expanded. Increasing (maintaining, reducing migration) the number of small farms, which *per se* are assumed to be less energy consuming, eventually is a better policy than just a policy of directed energy consumption towards a lower energy consumption on existing farms. Note that we went for the standard argument that labour replaces energy and vice versa in sectors. But we will aim also at structural changes on the land market. From re-specification of production economics and decision-making towards land demand we get:

$$\lambda_{e,l} = Q^{*}_{32} A\, l_1 + Q^{*}_{32}\, \mathrm{c}_{l,-l} + Q^{*}_{33}\, c_{e,l} + Q^{*}_{34}\, c_{t,l}, \tag{8a}$$

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

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 obtain 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 using energy criteria. Technologies, output prices and constraints determine the rent. We have to think about combining policy instruments to boost less energy-intensive farms.

Objectives of government

As a way to specify the objective and the constrained behavioral functions of the government, we can use a concept which is similar to those of a principal and agents (Richter, 1997); whereby we consider the farm sectors as agents which are reflected by the behavioural functions. The instrument variables prevailing are *s* and *t* impacting on *h* and *r*. Furthermore, we have to clarify the objective. A simple version of a principal is that he wants to maximize the net effects of reduction of energy use at a given amount of money available; or he minimizes the money spent for energy use reduction, assuming a given target of CO_2 emission. In our case, it is an economic cost benefit analysis to find shadow prices. We assume a target of reducing e_t which is supposed to be achieved by several instruments.

The target is a change in savings in costs of carbon emission (measure in fossil energy use equivalents) given as an unweighted function of reduction ($e_t = e_{l,r} + e_{s,r} + e_{u,r}$) which shall have a quadratic feature (in principle, it means that there is a marginal value of the demand function for reduction: alternatively, one can work also with fixed prices):

$$\begin{aligned} E_r = {} & \zeta_0\, [e_{l,r} + e_{s,r} + e_{u,r}] + 0.5\, [e_{l,r} + e_{s,r} + e_{u,r}]^{‘} \\ & \zeta_1\, [e_{l,r} + e_{s,r} + e_{u,r}] - t^{‘}\, h - s^{’}\, r, \end{aligned} \tag{9a}$$

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 are presented in a function:

$$\begin{aligned} & A_l\, [e_{l,r} + e_{s,r} + e_{u,r}]' = b_{l,0} + B_l\, [t, s]' \Longleftrightarrow \\ & [e_{l,r} + e_{s,r} + e_{u,r}]' = A_l^{-1}\, [b_{l,0} + B_l\, [t, s]'] \end{aligned} \tag{9b}$$

and

$$\begin{aligned} & A_2\, [h, r]' = b_{l,0} + B_l\, [t, s]' \Longleftrightarrow \\ & [h, r]' = A_2^{-1}\, [b_{l,0} + B_l\, [t, s]'], \end{aligned} \tag{9c}$$

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

Insertining constraints 9b and c in (9a) gives a variable reduction of the policy instruments *t* and *s*. Finally, an objective to be maximized as (10) is obrtained:

$$\begin{aligned} & E_r = \zeta_0'\, A_l^{-1}\, [b_{l,0} + B_l\, [t, s]'] + 5\, [b_{l,0} + B_l\, [t, s]']' \Longleftrightarrow \\ & A_l^{-1'} \zeta_1\, A_l^{-1}\, [b_{l,0} + B_l\, [t, s]'] - [t, s]\, A_2^{-1}\, [b_{l,0} + B_l\, [t, s]']. \end{aligned} \tag{10}$$

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

CONCLUSIONS

As was shown, one can address the issue of excessive energy use on large farms by the modeling of technology choice. Our choice modeling of technologies included a tax on energy use embedded in the technology. Alternatively, small farms pursue the technologies that are labour-intensive, and it has been shown how subsidies for labour can be part of the analysis. In this respect, we have presented a modeling approach to how economies of scale in large farms and recycling in small farms can be guided by policy instruments such as energy taxes and recycling subsidies.

As a result, energy use in agriculture could be reduced as it becomes subject to policy instruments. For the analysis, we assumed diminishing returns from the reduction of energy use in agriculture and referred to the negative effects of excessive energy use and corresponding carbon dioxide emissions. The result is a policy analysis where taxes and subsidies are used to reduce carbon emissions from agriculture and contribute to climate change reduction. For the individual segment of large farms, a tax is collected according to the scale, size of operation obtainable from machinery use. For small farms we suggested a subsidy on recycling and indicated how savings of nitrogen produced by fossil energy use reduce carbon emission. One major insight of the analysis is a new mode of introduction of an energy tax as a switch between technologies. Since economies of scale are realized by technology jumps and these jumps describe shifts to energy-intensive practices, a new behavioural concept is applied.

Another insight is how, by modeling the policy, we can address direct and indirect effects of taxes and subsidies. With regard to direct policy effects, the tax will impact energy, and the subsidy promotes recycling. With regard to indirect effects, the share of (either) large-or small-scale farming will change. To conclude, with regard to competiveness, the tax and subsidy will change land occupation as a structural policy variable. Finally, it is indicated how tax and subsidy can be optimized using an objective function of carbon and climate costs.

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Ernst-August Nuppenau

EKONOMIKA, ENERGIJOS SUVARTOJIMAS IR ĮMONIŲ DYDIS ŽEMĖS ŪKIO SEKTORIUJE: POLITIKOS FORMAVIMAS, SIEKIANT SUMAŽINTI ANGLIES DVIDEGINIO IR ŠILTNAMIO DUJŲ EMISIJĄ

Santrauka

Paprastai stambieji ūkiai sunaudoja daugiau energijos, ir jų darbo našumas būna didesnis, palyginus su smulkiaisiais, o tai ir yra jų pranašumas. Šiame straipsnyje analizuojama, kaip modeliuoti bei naujoviškai vystyti stambiuosius ūkius ir pasirinkti technologijas, skatinant taupyti energiją ir plėtoti abiejų rūšių ūkius. Kyla klausimas, kaip spręsti ūkių dydžio ir energijos suvartojimo problemas per mokesčių ir rėmimo sistemas, siekiant sumažinti anglies emisiją žemės ūkyje? Siūloma linijinio programavimo struktūra ir kvadratinis ūkių veiklos išdėstymas, siekiant nustatyti optimalų ūkio veiklos modelį, atsižvelgiant į įvairius stambiųjų ir smulkiųjų ūkių segmentus darbo našumo, efektyvaus energijos panaudojimo ir perdirbimo atžvilgiu. Energijos suvartojimo pagrindu parodyta, kaip skiriasi optimizavimo galimybės ir ūkių struktūros. Tyrimo rezultatai yra ypač aktualūs ir vertingi Rytų Europos šalims, kurios susiduria su struktūrinių pokyčių uždaviniais ir stengiasi gauti paramą darniai žemės ūkio plėtrai Europos Sąjungoje.

Raktažodžiai: energijos suvartojimas, ūkio dydis, technologijos ir žemės ūkio politikos