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Is Organic Farming Inefficient, or Are Indicators of Economic Performance of Agriculture Incomplete?

Anni Huhtala

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Anni Huhtala

MTT Economic Research
Agrifood Research Finland
Luutnantintie 13, FIN-00410, Helsinki, Finland
anni.huhtala@mtt.fi

Abstract. Organic farming is expected to alleviate the environmental burden of agriculture, since it rules out the use of chemicals such as synthetic fertilizers, pesticides, herbicides. However, organic farming technology may turn out to be less efficient when evaluated by conventional productivity measures that are less informative regarding environmental efficiency. We derive a framework for a combination of more comprehensive indicators reflecting whether organic farming increases sustainability in agriculture and how much of the total agricultural value added is produced at the expense of environmental deterioration. We show that it is important to separate flow and stock effects of pollution so that aggregate measurement is consistent with conventional national accounting. Shadow pricing of undesirable output and policy implications are discussed. For adoption of a technology and allocative efficiency in the agricultural sector, economic policy instruments should be redesigned and proper incentives through prices should be used.

Index words: national income accounting, environmental efficiency, technology choices
JEL Codes: H23, O47, Q18, Q25

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1 Introduction

The European Commission has recently made a proposal to reform the Common Agricultural Policy (COM (2003) 23 final). It is claimed that the major objective of the reform is to give farmers a long-term perspective for sustainable agriculture. In particular, the implementation of the Commission reform would remove environmentally negative incentives and provide further encouragement for more sustainable farming practices.

In line with the development of political climate towards a sustainable agriculture, organic farming has become an important option for policies promoting food safety and environmental quality of food production. There seems to be obvious political pressure to increase the adoption of organic farming technology, and the Council of the European Union proposes, among other things, that numbers of organic farms and area devoted to organic farming should be included in the list of environment-related headline indicators of EU (COM (2002) 524 final). The motivation is that by ruling out the use of synthetic fertilizers and other chemicals such as pesticides and herbicides (e.g. Zanoli and Gambelli 1999) organic farming represents an environmentally ‘clean’ technology in agriculture. The organic farming technology has, nevertheless, developed with only little input from scientific research (Lampkin et al. 1999), and it can be viewed as a constrained version of conventional farming. In addition, the potential environmental friendliness does not come without a cost. Yields in organic farming are in general significantly lower than under conventional management, even though the yield differences vary between products and to a certain extent between countries (Offerman and Nieberg, 2000).

Organic farming as a policy issue should be placed in the current context of international development of agricultural sector. Depending on the farming strategies adopted also the environmental impacts will change accordingly. It is necessary to evaluate the existing measures of economic performance of conventional and organic farming technologies from a point of view of environment, since conventional economic indicators may be misguided. We consider, in particular, the applicability of efficiency indices and welfare accounting as sustainability indicators for agricultural sector.

Agricultural income (value added) forms part of conventional national income accounting. When a Net National Product (NNP) is calculated in practice, the measurement of economic activity is based on market transactions and market prices. However, consumption commodities differ in their attributes and, at least in principle, the environmental impacts of products can be traced back to the technology used in the production. Different production technologies imply different environmental performance, and this should be reflected in welfare accounting. The same is true for productivity measurement. What is crucial to notice in decision making it that productivity measurement involves commonly used economic efficiency measures that are variant to the prevailing prices. This may be a problem for evaluation of sustainability, since market prices of final products do not capture social costs or benefits such as environmental quality. Our analysis seeks to develop more comprehensive indicators of sustainability in agriculture for policy makers by showing how the conventional indicators of economic performance should be completed.

In previous literature Hrubovcak et al. (2000) have developed a theoretical framework to incorporate the environmental impacts of agricultural production into the existing income accounts. Here, we take a step further in our analysis and introduce organic farming as an alternative technology. We also discuss why the commonly applied modeling of environmental stocks as part of utility function may be problematic for 'green' accounting[1] due to inconsistency with the income accounting principles.

Another line of literature of evaluation of efficiency has in fact developed approaches to gain information on social costs associated with production; firms' environmental performance is measured with efficiency indexes that include undesirable outputs[2]. These methods are not always applicable, though (see, e.g., Smith 1998). The current empirical literature on the efficiency of organic farming is rather limited, mainly because there have not been sufficient data on organic farms. The existing rare studies on comparison of the performance of organic and conventional farms also provide to some extent contradictory results on how efficient organic farming technology is in using natural resources (e.g. Stolze et al. 2000, Grönroos and Seppälä 2000, Oude Lansink et al. 2002).

[1] For a good overview of much of the green accounting literature, see Heal and Kriström (2002).

[2] Modeling of productivity and undesirable outputs originated with the work by Pittman (1983) which has later been extended into various approaches; see, e.g., Färe et al. (1989). Tyteca (1997) gives an overview with a comprehensive bibliography.

Here, we provide a systematic framework for economic efficiency measurement including environmental impacts. We show also that there is a link from measurement of agricultural value added to efficiency measurement at the farm level, since both indicators require some form of shadow pricing of direct disutility of environmental deterioration. We aim to improve the policy relevance of the aggregate welfare indicators regarding the economic and environmental features of organic farming. In addition, the indicators derived here should be applicable to comparison of alternative technologies also in other industries than agriculture. The framework also sheds light on how prevailing conditions are reflected in existing indicators and they do not support or provide incentives for adoption of new environmental friendly technologies.

The paper is organized as follows. In section 2, we present a simple growth model in which pollution (run-off of nutrients, leaching of pesticides) is a source of inefficiency and capital stock incorporates the manufactured means of production (equipment). For the sake of comparison we separate two different types of technology specific capital stocks, and an additional stock is included in the analysis to capture the dynamics of environmental deterioration. Section 3 illustrates the implications for output (NNP) and efficiency measurement, given that there are differences in economic and environmental performance between farms using alternative technologies. In section 4, the implementation of policies to attain socially optimal farming strategies is discussed. Section 5 concludes.

2 Derivation of a socially optimal outcome

Our analytical framework starts from national accounting to identify the components of value added generating growth in the agricultural sector. The framework is based on the result of Weitzman (1976) which proves how net national welfare measurement can be theoretically justified. The well-known result states the valuation principle for an economy maximizing utility subject to capital stock over time. Formally, a first best optimal solution can be derived by setting up a social planner's utility maximization problem over time. Utility is derived from consumption, C, whereas the accumulation of capital, $dk/dt = f(.) - C - \delta k$, is determined by total output, $f(k)$, minus consumption and depreciation of capital, i.e., investments. As shown by Weitzman, a linear support of the Hamiltonian along the optimal path corresponds to national welfare, or $NNP=C+I$. We use the above accounting rule as a guiding principle to build up an output measurement framework for the agricultural sector. The basic model will be completed with environmental impacts of production.

The agricultural sector produces goods C and G by using conventional and organic farming technology, respectively. Chemicals (e.g., artificial fertilizers, pesticides), N, are used as inputs in conventional farming, and a proportion α of the total use of chemicals shows up as nuisance in the utility function. The nuisance, or disutility can be, e.g., spoiled recreation possibilities due to water pollution or negative health effects due to toxicity. Utility function takes the form $U(C,G,\alpha N)$ with $U_C>0$, $U_G>0$, and $U_N<0$, and it is strictly increasing, strongly concave and discounted over time by a constant social interest rate, $r > 0$.

We posit two production functions which involve both organic production, $g(K_2, L_2, A_2)$, and conventional production, $f(K_1,N, L_1, A_1)$. Both technologies utilize capital (K_1,, K_2), labor (L_1,, L_2), and land (A_1,, A_2) which are sector specific inputs. The main difference in the production functions is the use of synthetic chemicals which are banned in organic farming. Synthetic substances are used only in conventional farming, and an excess use of chemicals leads to undesirable residues, runoff and leaching of nutrients and/or pesticides, αN.

On the other hand, one of the key points of organic farming is the increase, or at least maintenance of soil fertility on a long-term basis. Since chemicals are not allowed to be used, organic farming relies on crop rotation which contributes positively to the soil fertility. To capture a potentially positive long-term impact of organic farming, G, we describe the deterioration of environmental conditions (soil, water quality) as a dynamic process with an equation of motion $dW/dt=\alpha N - G$. Given that the economy places value on a long-term sustainability in agriculture, the changes in these environmental conditions should be taken into account.

Let us now set up the social planner's optimization problem over time. The objective function

$$\int_o^\infty U(C,G,\alpha N)e^{-rt}dt$$

is to be maximized subject to the equations of motion for capital stocks in conventional, K_1, and organic, K_2, production

(1) $\dot{K}_1 = f(K_1, N, L_1, A_1) - C - \delta_1 K_1$

(2) $\dot{K}_2 = g(K_2, L_2, A_2) - B - \delta_2 K_2$

and subject to additional input constraints of the total land area available, $\overline{A}$ (including other than agricultural land use, A_3)

(3) $\overline{A} = A_1 + A_2 + A_3$

and subject to the total amount of labor available, $\overline{L}$ (including non-agricultural activities, L3)

(4) $\overline{L} = L_1 + L_2 + L_3$

and finally subject to the equation of motion of environmental deterioration

(5) $\dot{W} = \alpha N - G$.

For the maximization problem of the social planner, we write the Lagrangian

(6) $$\begin{aligned} \ell &= U(C, G, \alpha N) + \lambda_1 (f(K_1, N, L_1, A_1) - C - \delta_1 K_1) + \lambda_2 (g(K_2, L_2, A_2) - B - \delta_2 K_2) \\ &+ \varphi(\overline{A} - A_1 - A_2 - A_3) + \omega(\overline{L} - L_1 - L_2 - L_3) + \tau(\alpha N - G) \end{aligned}$$

and the first order conditions

(7) $\partial\ell / \partial C = U_C - \lambda_1 = 0$

(8) $\partial\ell / \partial G = U_G - \lambda_2 - \tau = 0$

(9) $\partial\ell / \partial L_1 = \lambda_1 f_{L_1} - \omega = 0$

(10) $\partial\ell / \partial L_2 = \lambda_2 g_{L_2} - \omega = 0$

(11) $\partial\ell / \partial A_1 = \lambda_1 f_{A_1} - \varphi = 0$

(12) $\partial\ell / \partial A_2 = \lambda_2 g_{A_2} - \varphi = 0$

(13) $\partial\ell / \partial N = \alpha U_N + \lambda_1 f_N + \tau\alpha = 0$

(14) $\dot{\lambda}_1 = \lambda_1 (r + \delta_1 - f_{K_1})$

(15) $\dot{\lambda}_2 = \lambda_2 (r + \delta_2 - g_{K_2})$

(16) $\dot{\tau} = r\tau$

(17) $\dot{K}_1 = f(K_1, N, L_1, A_1) - C - \delta_1 K_1$

(18) $\dot{K}_2 = g(K_2, L_2, A_2) - G - \delta_2 K_2$

(19) $\dot{W} = \alpha N - G$.

From (7), (9), (11) and (13) the optimality necessitates that

(20) $U_C = \dfrac{\omega}{f_{L_1}} = \dfrac{\varphi}{f_{A_1}} = \dfrac{-\alpha(U_N + \tau)}{f_N}$

to guarantee efficient input use in conventional farming. In particular, the use of chemicals is optimal up to the point where the utility value of the marginal productivity of chemicals equals the direct disutility (U_N) and the dynamic impact of environmental deterioration (τ) that are proportional to the use of chemicals (α).

Accordingly, equations (8), (10) and (12) determine optimal input use in organic farming

(21) $U_G = \tau + \dfrac{\omega}{g_{L_2}} = \tau + \dfrac{\varphi}{g_{A_2}}$.

Since the shadow price reflecting the environmental deterioration is negative, equation (21) means that organic farming technology should be employed up to the point where the direct production/input costs are exceeded by the amount of τ when the enhancement of environmental quality is properly taken into account. Consequently, how much of each technology should optimally be adopted is determined by

(22) $\dfrac{U_G - \tau}{U_C} = \dfrac{\lambda_2}{\lambda_1} = \dfrac{f_{L_1}}{g_{L_2}} = \dfrac{f_{A_1}}{g_{A_2}}$.

Organic farming should be favored at the expense of conventional farming because of its positive environmental impact which equals the amount of τ at the margin. This has been illustrated in Figure 1 which shows that optimal allocation of outputs produced by conventional and organic farming technology is dependent on relative prices (in terms of marginal utilities) and the shadow price τ. In section 4, we discuss the importance of correct prices for efficiency measurement, but before that we show how conventional economic indicators such as agricultural value added in national product and efficiency indexes based on farm level data may be misleading from an environmental point of view.

3 Why do conventional indicators of economic performance discriminate against clean technology?

We start by discussing first the implications of our choice to model pollution impacts as undesirable but unavoidable output and then derive explicitly an accounting framework for extended green accounts for agricultural sector. In our model, chemicals are a positive and necessary input in conventional farming (f_N>0), but an excessive use of the chemicals can have undesirable impacts in the long run, and these impacts are captured by a negative term in the utility function (αN). The flow of undesirable production becomes a source of inefficiency. In this respect, our model differs from the previous dynamic pollution models by, e.g., Aronsson and Löfgren (1999) (see also the references therein), which have been influenced by the model of Brock (1977). In Brock's model pollution enters as a separate argument, in the form of a stock, in the utility function and therefore inevitably decreases utility directly. A similar modeling of pollution in a purely mathematical sense is adopted in Hartwick (1990) where pollution stock is a negative argument in the production function. This, however, implies negative `preferences' on the part of firms towards pollution, which contrasts with the spirit adopted by Brock, who considers pollution as a positive input on the producers' side.

What is common to all of these previous models, however, is that the shadow value of pollution is determined by preferences towards the stock of pollution directly. This has an important implication for measurement practices in extended green national accounting. It means that the total stock of pollution should be valued annually. This in part contradicts the value added thinking in conventional national accounts. The (man-made) capital stock as such is never valued separately but the changes in the stock are. I.e., investments are a component of Net National Product (NNP), since investments form the actual annual value added. Logically, it is the flow of pollution, or undesirable production, not the stock, that enters the utility function in our modeling. As will become evident below, this gives more realistic possibilities to value or shadow price the negative environmental impacts associated with production.

(i) National accounting and measurement of undesirable output

Now we are in a position to derive a welfare measure that includes measurable environmental impacts. We linearize the utility function, $U(\cdot)$, and form the current value Hamiltonian from the optimization problem presented in section 2

$$\overline{\mathrm{H}}_{\tau} = U_C \cdot C + U_G \cdot G + \alpha U_N N + \lambda_1 \dot{K}_1 + \lambda_2 \dot{K}_2 + \tau \dot{W}$$

and using the first order conditions (13) and (19) we rewrite

$$\overline{\mathrm{H}}_{\tau} = U_C \cdot C + U_G \cdot G - U_C f_N N - \tau\alpha N + \lambda_1 \dot{K}_1 + \lambda_2 \dot{K}_2 + \tau(\alpha N - B).$$

Dividing the linearized current value Hamiltonian by λ_1 (= U_C), we arrive at a monetary value measure of a green NNP

$$\overline{G}\overline{NNP}_{\tau} = C - f_N N + p_{G\tau} \cdot G + \dot{K}_1 + p_{G\tau} \cdot \dot{K}_2 \qquad (23)$$

where$(U_G\text{-}\tau)/U_C$ is denoted by $p_{G\tau}$.

The conventional NNP is defined as consumption plus net investment evaluated at market prices. In equation (23), *C* and *G* stand for consumption of *measured* desirable output, pollution excluded. However, the conventional NNP should be adjusted to account for environmental consumption and its impact on the Hicksian concept of income, or the maximum amount that can be consumed while still leaving capital intact. The above equation suggests two adjustments: the contribution of nutrients should be deducted from national product, $f_N N$, and market prices of organic products should be corrected with τ. We discuss the shadow price and price corrections more thoroughly in the next section, since socially non-optimal market prices have strong implications for conventional efficiency measurement and evaluation of productivity. Instead, we focus on the overall downward adjustment of NNP here.

As for deduction of $f_N N$ from national product, the logic becomes evident from equation (13). In optimum $f_N = -\alpha(U_N + \tau)/U_C$ which tells that the productivity of synthetic fertilizers must be equal to the disutility of their negative environmental impacts. That is why the undesirable, but unavoidable pollution flow, or a negative environmental impact can be valued using f_N. This has been illustrated in Figure 2 where the output combination (C_o,G_o) is produced at the expense of a chemical flow N_o. The environmentally adjusted NNP derived above suggests that the conventionally measured NNP exaggerates the positive contribution of production. For a more comprehensive measure of annual production, environmental effects should included. First, the environmentally harmful output measured by the amount of N and valued by f_N should be taken into account. Second, the market prices should be corrected for the shadow price of environmental deterioration. The latter is particularly important for policy making, since if the prices will not be corrected, there will be no incentive to adopt the optimal amount of environmental friendly technology. Consequently, the conventional measures of economic efficiency will misleadingly indicate the more environmentally friendly technology (organic farming) to be less efficient than the conventional one. This will be discussed in the following.

(ii) Efficiency indexes and market prices of good commodities

The previous literature of production theory involves a number of commonly used efficiency measures to evaluate firm-level economic performance (see, e.g., Battese 1992, Fried et al. 1993). The measures are calculated relative to a given technology, which is generally represented by some form of frontier function. Here we will use output-orientated measures for our illustration of potential environmental biases in conventional measures.

Let us consider the case where production involves two outputs (C and G) and a single input (L). Holding the input quantity fixed at a particular level ($L = \overline{L}$) we can represent the technology by a production possibility in two dimensions. In Figure 3 the line HH' is the production possibility curve which represent the upper bound of production possibilities. Therefore, an economy operating at the point A is inefficient, since the output combination of A lies below the curve.

The distance AA' represents *technical inefficiency*, or the amount by which outputs could be increased without requiring extra input. Hence, a measure of output-orientated technical efficiency is the ratio OA/OA'. Given that we have price information for C and G, we can define the allocative efficiency with the help of the isorevenue line JJ' as OA'/OA^m. Finally, overall *economic efficiency* is the product of these two measures, $(OA/OA')x(OA'/OA^m)$. (See Coelli et al 1998, Chapter 6).

What can be noted from the efficiency measures defined above is that the measures of allocative and overall economic efficiency are variant to the prevailing prices. As was shown in section 2 the socially optimal prices may deviate from market prices, and environmentally less harmful production technologies are deemed to be less efficient when market prices are used. This can be seen from Figure 3 by drawing a new isorevenue line KK' which corresponds to socially optimal price ratio adjusted by τ. Changing the prices would improve the measure of economic efficiency of organic farming, and corresponding to the point A the measure would become $(OA/OA')x(OA'/OA^s)$.

At this point we should comment the most recent development in modern efficiency measurement which has already been extended to include undesirable, polluting commodities that are outputs from some production process (see, e.g., Färe and Grosskopf 1998). In particular, the latest approaches can be used to derive explicitly shadow prices for polluting outputs (see, e.g., Färe et al. 2002). However, these methods allow efficiency comparisons between decision making units (firms, farms) only in cases where pollution is an unavoidable by-product and no environmentally clean technologies exist. In our example, organic farming is, by definition, a totally clean technology in the sense that the use of synthetic chemicals is ruled out. Therefore, we need a measure acknowledging this kind of total input discrimination in organic farming vis-a-vis other production technologies in agriculture. In addition, computation of shadow prices in the context of efficiency measurement normally imposes implicit constraints on the value of shadow prices. (See e.g., Färe et al. 2002) The valuation is implicitly done during the course of formalization of the objective function by deciding beforehand how large a reduction in the undesirable output is wanted with respect to an increase in the desirable output. This fact has not been emphasized in the previous shadow pricing literature, though.

We have shown how both the aggregate income accounting (NNP) and the micro-level efficiency measures may be misleading indicators, since they fail to give credit for efforts advancing sustainability. Now the question is how the socially optimal outcome could be implemented.

4 Improving the indicators of economic and environmental performance and implementing the socially optimal outcome

It is evident from above that both the measurement of output (welfare accounting) and economic performance (efficiency indexes) should be developed further if they were to be used as indicators of productivity and environmental sustainability of agricultural sector. However, the challenge is more complicated than just making adjustments in conventional measures to create more appropriate indicators for policy makers. The adjustments should be internalized in prices of commodities exchanged in the marketplace.

Following the tradition in literature on social planner's optimal control, it can be shown how the socially optimal solution can be attained in a market economy. The derivation of the optimal conditions for a controlled market economy is straightforward and derived several times in different contexts in the previous literature (for hints see, e.g., Tahvonen and Kuuluvainen 1993, Aronsson and Löfgren 1999). In our example, the optimal economic instruments that should used to reach a socially optimal solution necessitates a tax (t_N) on the use of chemicals and a subsidy (s_G) on commodities produced by organic farming technology. An optimal pollution tax would be $t_N = -\alpha(U_N + \tau^*)/\lambda_1^*$ and an optimal commodity subsidy $s_G = \tau^*/\lambda_2^*$ where τ^* is the shadow price of environmental deterioration, λ_1^* is the shadow price of capital in conventional farming, and λ_1^* is the shadow price of capital in organic farming.

From the first order condition (13) an optimal value of the shadow price of environmental deterioration is $\tau^* = -U_N - U_C f_N/\alpha$ which is the difference between a direct welfare effect and a productivity effect contributing to the production of desirable output. The latter can be more easily measured from market data but for the evaluation of direct disutility other environmental valuation methods are called for (such as stated preference methods; see, e.g., Braden and Kolstad 1992).

After valuation of both components of τ, optimal policy could be implemented with the help of economic instruments presented above. It should be emphasized that nothing guarantees that optimal taxes and subsidies balance the government budget. In contrary, it is highly unlikely that the total tax revenues ($t_N \cdot N$) would equal the total subsidy payments ($s_G \cdot G$) in a socially optimizing economy. In practice, given the current income structure and large subventions in agriculture, economic instruments should be redesigned to give proper incentives to attain socially optimal environmental quality. To reach other socially important targets such as sustainable distribution of income non-distorting lump-sum transfers should be used from a point of view of environmental policy. Therefore, it would be interesting to study how the optimal and budget-balancing policies differ in terms of adoption of clean technologies. An overall evaluation of government tax policy is too broad an issue to be tackled here, though.

In any case, for the economic indicators to be more comprehensive from a point of view of environmental deterioration they should be derived using correct social cost information. In welfare accounting, output of organic production would be valued using the socially optimal prices. The corrected prices should also be used when evaluating the allocative and economic efficiency of organic production.

5. Conclusions

The implications derived here are valid for any choice between conventional and environmentally clean technology: too little is produced by clean technology and too much under conventional management practices.

Our theoretical framework for national accounting takes into account environmental impacts of alternative production technologies in agriculture. A formalized optimization problem helps to keep track of direct and indirect environmental effects. In particular, the productivity of polluting input must equal the direct disutility of pollution (e.g., nuisance impacts on recreation through water quality, toxicity impacts on human health) and the dynamic effect of a deterioration of the environment over time.

An important issue is the practical valuation of negative environmental impacts: many pollution impacts can be valued or estimated using opportunity costs, but not all of them. Computation of shadow prices in the context of efficiency measurement normally imposes implicit constraints on the value of shadow prices. The valuation is implicitly done during the course of formalization of the optimization problem by deciding beforehand the ratio in which the undesirable output is reduced and the desirable output increased. This should be emphasized more clearly in the shadow pricing literature.

However, we should look more carefully at environmental effects of alternative production technologies, especially the quantitative data on inputs that are transformed to undesirable outputs during the production process. By considering pollution as a source of inefficiency in an economy, we take into account the external effects of production on the state of the environment. Trade-offs between economic efficiency vs. environmental efficiency can be explored appropriately.

In addition, we have pointed out that inclusion of environmental stocks as part of utility function may be problematic for interpretation of extended 'green' national accounts. In the previous literature, the growth models used to derive green welfare measures theoretically have at least implicitly required the valuation of the total pollution stock to capture environmental impacts. This is not in the spirit of annual income accounting principles of measuring only investments, not (capital) stocks as such.

Finally, it should be emphasized that nothing guarantees that the environmentally optimal taxes and subsidies suggested here balance the government budget. In practice, this is a result of political compromising. The current income structure and subventions in agriculture notwithstanding, economic policy instruments could be redesigned to give proper incentives to attain socially optimal environmental quality.

Figure 1.

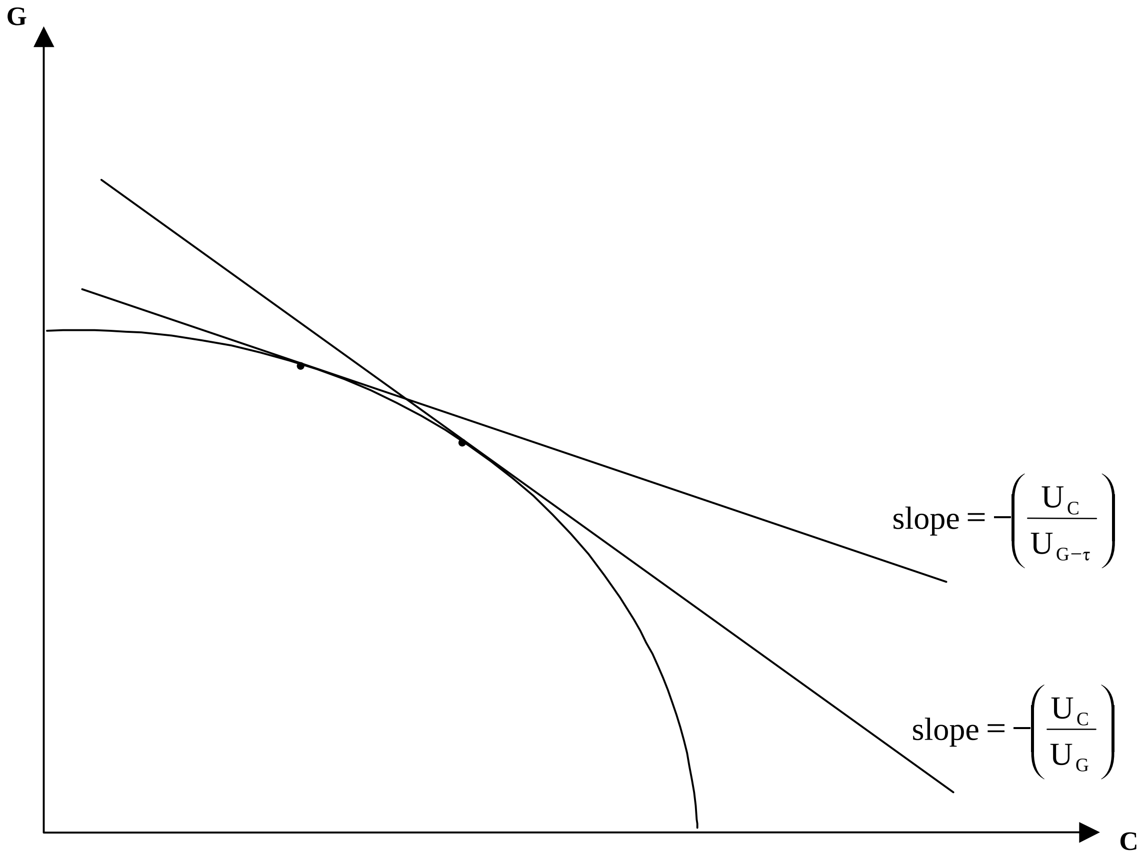
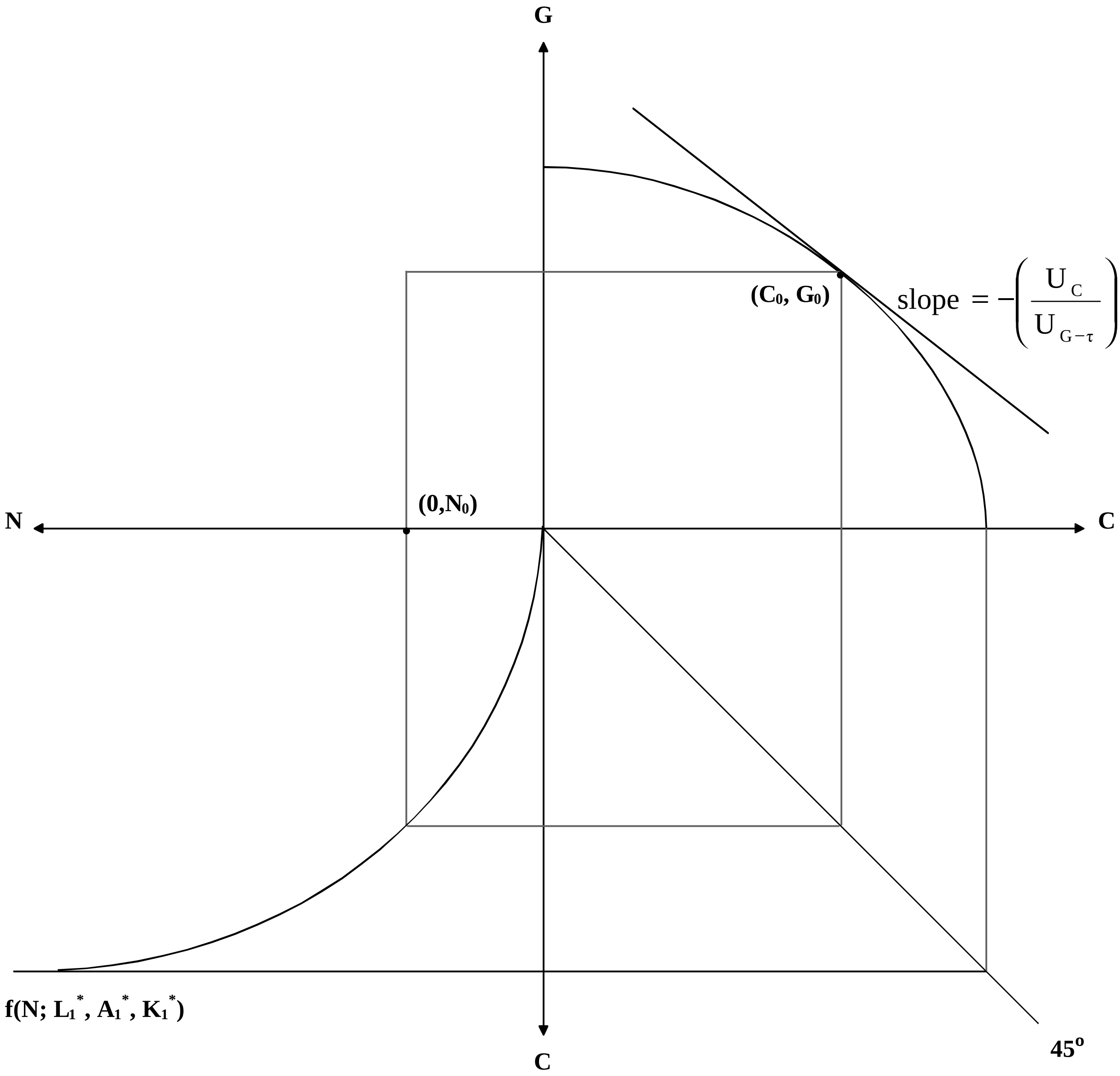
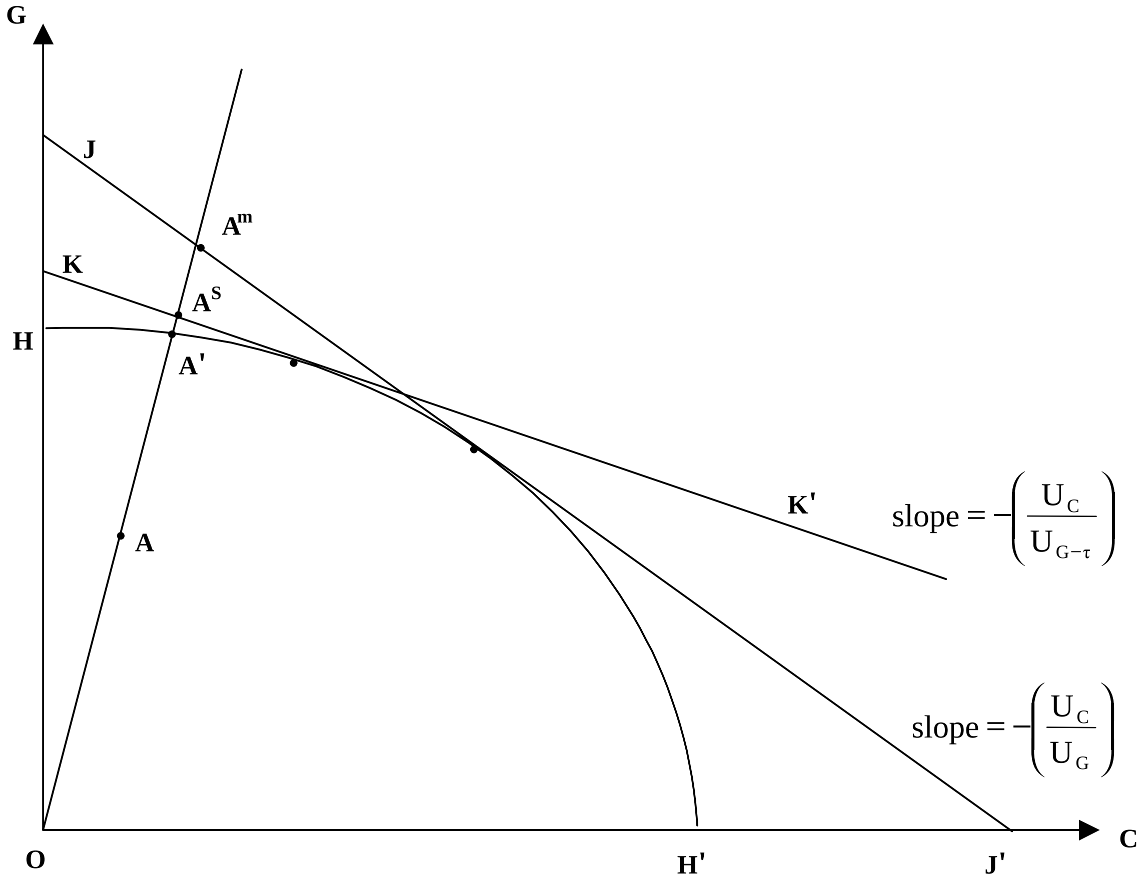


Figure 2.



G = output produced by organic farming
C = output produced by conventional farming
N = use of chemicals

Figure 3.


G
J
A^m
K
A^S
H
A'
K'
slope = $-\left(\frac{U_C}{U_{G-\tau}}\right)$
A
slope = $-\left(\frac{U_C}{U_G}\right)$
C
O
H'
J'

References

Aronsson, T. and K.-G. Löfgren (1999). Pollution Tax Design and `Green' National Accounting, *European Economic Review* 43(8):1457-1474.

Battese, G.E. (1992) Frontier Production Functions and Technical Efficiency: A Survey of Empirical Applications in Agricultural Economics, *Agricultural Economics* 7:185-208.

Braden, J.B. and C.D. Kolstad (1992) *Measuring the Demand for Environmental Quality*. North-Holland, New York.

Brock, W. (1977).A Polluted Golden Age, in V. L. Smith (ed.), *Economics of Natural and Environmental Resources*, Gorden and Breach, New York.

COM (2002) 524 final. Analysis of the ”open list” of environment-related headline indicators. Report from the Commission to the Council.

COM (2003) 23 final. CAP Reform A long term perspective for sustainable agriculture. Proposal for Council Regulation presented by the Commission.

Fried, H.O., Lovell, C.A.K and S.S. Schmidt (1993). *The Measurement of Productive Efficiency: Techniques and Applications*, Oxford University Press, New York.

Färe, R. and S. Grosskopf (1998). Shadow Pricing of Good and Bad Commodities, *American Journal of Agricultural Economics* 80: 584-590.

Färe, R., Grosskopf, S., Lovell, C. A. K. and C. Pasurka, (1989). Multiple productivity comparisons when some outputs are undesirable: a nonparametric approach, *The Review of Economics and Statistics* 71: 90-98.

Grönroos, J. and J. Seppälä (2000). *Maatalouden tuotantotavat ja ympäristö (Agricultural production practices and the environment).* Finnish Environment Institute, Helsinki. In Finnish, Executive Summary in English.

Hartwick, J.M. (1990). Natural Resources, National Accounting and Economic Depreciation, *Journal of Public Economics* 43: 291-304.

Heal, G. and B. Kriström (2002). “*Green Accounting”*, forthcoming in: Mäler, K.-G. and J. Vincent (eds.), *Handbook of Environmental Economics*, North Holland, Amsterdam.

Hrubovcak, J., M. LeBlanc, and B.K. Eakin (2000). Agriculture, Natural Resources and Environmental Accounting, *Environmental and Resource Economics* 17:145-162.

Lampkin, N., C. Foster, S. Padel and P. Midmore (1999) The policy and regulatory environment for organic farming in Europe, *Organic farming in Europe: Economics and Policy* 1:1-166.

Offermann, F. and H. Nieberg (2000) Economic performance of organic farms in Europe, *Organic farming in Europe: Economics and Policy* 5:1-198.

Oude Lansink, A., Pietola, K. and S. Bäckman (2002) Efficiency and productivity of Conventional and organic Farms in Finland 1994-1997 *European Review of Agricultural Economics* 29: 51-65.

Pittman, R.W. (1983). Multilateral productivity comparisons with undesirable outputs, *The Economic Journal* 93: 883-891.

Smith, V.K. (1998). Should Pollution Reductions Count as Productivity Gains for Agriculture, *American Journal of Agricultural Economics* 80: 591-594.

Stolze, M., A. Piorr, A. Häring, and S. Dabbert (2000) Environmental Impacts of organic farming in Europe, *Organic farming in Europe: Economics and Policy* 6:1-127.

Tyteca, D. (1997) Linear Programming Models for the Measurement of Environmental Performance of Firms: Concepts and Empirical results, *Journal of Productivity Analysis*, 8; 183-197.

Weitzman, W.L., (1976). On the Welfare Significance of National Product in a Dynamic Economy, *Quarterly Journal of Economics* 90: 156-162.

Zanoli, R. and D. Gambelli (1999) Output and public expenditure implications of the development of organic farming in Europe, *Organic farming in Europe: Economics and Policy* 4:1-66.