VIABILITY THEORY AND SOIL DEVELOPMENT

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Summary

We utilize Viability theory to evaluate the effects of CAP. A differential equation describes the dynamic development of soil productivity. If farmers do without entitlement, they are free in soil handling. And as we assume they are short-term profit maximizers, they miss to pay attention to soil conservation. Soil productivity is at risk; correspondingly, economic sustainability is at risk.

But if farmers activate their entitlements, they become obliged to soil conserving measures.

The model demonstrates that the decision to participate or not at the “entitlement & cross compliance”-program, depends on payment-level and the effects of the decision depend on the dynamics of the environmental system.

Keywords

Sustainability, Agriculture, Viability Theory

1 Introduction

The paper applies P. Aubin’s Viability theory to evaluate qualitative effects of the Common Agricultural Policy (CAP). Aubin introduced Viability theory more then 20 years ago; he (AUBIN, 2002) cites Monod to motivate his theory, who himself cites Democritus “Everything that exists in the universe is due to chance and necessity” (Democritus , 460–370 BC). Therefore, Aubin’s theory links these components to each other: the ecological chances, here soil productivity, and the economical necessities, here non-negative profits in agriculture.

In the course of new targets for the CAP, the mid-term-review of 2003, and the introduced cross-compliance rules (CC) as well as through adequate agri-environmental programs, soil conservation became a major issue[2]. Concerning Germany, four years earlier the ‘Bundesbodenschutzgesetz (BBodSchG’) had come into force, which denotes soil as one of the central elements of the ecosystem and stresses the responsibility in soil handling. In the same year the ‘Bundesbodenschutz und Altlastenverordnung (BBodSchV)’ became enactive, and in Bavaria the ‘Bayerisches Bodenschutzgesetz (BayBodSchG)’, which deals e.g. with a soil information system (BIS) and who’s implementation through the ‘Bodenschutz und Altlastenrecht in Bayern (BayBodSchVwV)’ was in 2000 (STMUGV (2006b)). Beginning 2005 another enactment became effective in Germany, conditioning direct payments on good agricultural practice in form of erosion omission, preservation of soil structure and landscape elements like hedges, rains, green corridors etc. and care for set aside acreages (BUNDESGESETZBLATT, 2004). And one year later the Commission of the European Communities published an “Impact assessment of the thematic strategy on soil protection”. In a body, the essential importance of soil became put in awareness.

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[2] The general importance of soil conservation has been emphasised already some decades before in the famous work “Beyond the limits” which advised public against environmental degradation as an essential danger for the future of humanity. Only few year earlier, the also well known Brundtland report “Our common future” listed the same aspect as threat for mankind.

Almost every form of soil degradation is accompanied by a loss of fertile soil (e.g. through erosion, (STMUGV, 2006a, BML, 2000)) and a loss in soil fertility (e.g. through compression and loss of micro organisms (STMUGV, 2006a, BML, 2000)). Therefore, in case of agricultural usage, soil degradation reduces agricultural income. Then again, agriculture is a core user of soil and itself had contributed a lot to soil degradation in Europe.

The processing within the paper is as follows: chapter 2 introduces the ecological and economical aspects under consideration, and identifies admissible evolutions. Further it looks at the viability kernel. Chapter 3 investigates the effects of the new CAP. Within the paper we concentrate on the influence of abandoned price support and compensating entitlements which are tied to accompanying soil conserving requirements. Chapter 4 summarizes the results and chapter 5 suggests some promising extensions of the analysis.

2 Viability-Models

Viability theory was intended as an alternative to control theory but during its development turned out to be connected to it. As an alternative to control theory it omits inter-temporal optimisation with respect to constraints which specify the development of the state. It emphasises economical requirements defining admissible evolutions. Through the addition of ecological principles, the induced future evolution comes into deal. The basic target is to stay within the economic constraints forever[3], which may be possible through different evolutions, or only through one unique evolution or which may be impossible through any evolution.

2.1 The ecological part

'Soil productivity' will be interpreted as an expression for more general natural environmental conditions, including soil quality, structure and nutrient content as well as moisture. Unfortunately, due to missing estimates about the ecological relationships, we cannot specify the differential equation for environmental development[4]. Therefore, we have to concentrate on a qualitative analysis, i.e. utilize the concept of qualitative differential equations, QDE (EISENACK, 2001, 2004, 2005).

Soil productivity development $\dot{B}$ depends on two arguments: on the crop output per hectare, y, and on the actual soil productivity B[5]. The first has negative influence on the development, the second positive influence:

(1) $$\dot{B} = f(\underset{(-)}{y}, \underset{(+)}{B})$$

The dependence of $\dot{B}$ on B might be a debatable assumption. We assume soil once becoming vulnerable to erosion through wind and water degrades faster than well preserved soil. I.e. a degradation process speeds up with an already realized productivity decline[6,7].

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[3] Insofar it is different from the Tolerable Windows Approach (TW), another alternative to control theory, which proceeds 'backward' and emphasis firstly the ecological view (PETSCHEL-HELD ET AL., 1999b).

[4] The general soil erosion equation (STMUGV, 2006a) does not take into account all types of productivity losses. STMUGV (2006b) illustrates the need for further documentation about soil quality and –threats, although the soil information system BIS already holds some accessible data and maps. Also EUROGEOSURVEYS, 2005, emphasises the need for soil monitoring and additional information about soil quality.

[5] E.g. once compression started, micro organism population decreases, and compression enforces even faster etc.

[6] It is an assumption different from the soil development equation in the Sahara Syndrome Model (EISENACK, 2005, PETSCHEL-HELD ET AL., 1999a). They assume soil development is exclusively determined by agricultural activity, which itself is motivated by poverty, a function of activity and soil quality.

[7] The function *f* itself depends on the applied cultivation technique. Cultivation techniques experience ongoing technical progress.

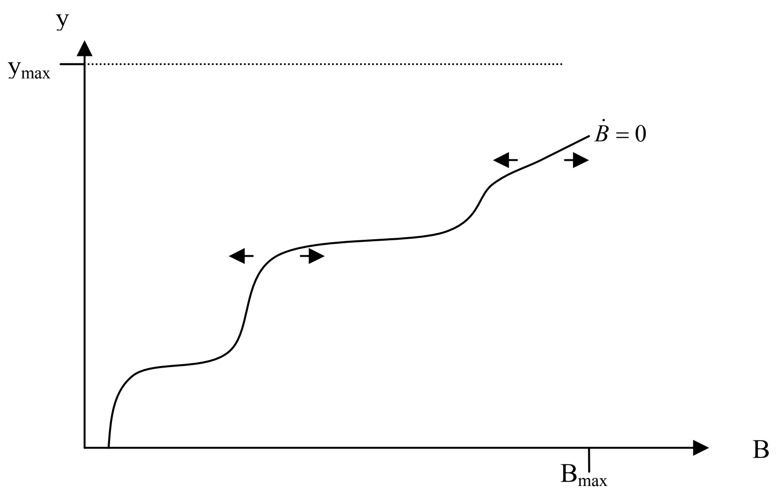
Further, well preserved soil needs more or less none or only very few special measures to stay productive. And if vegetable croup material remains on the field (or better mulched into the ground), humus can develop and soil productivity improves[8]. The same is true for non-devastated soils abandoned from production. Therefore, more intensive farming has a negative effect on $\dot{B}$, and less intensive farming a positive effect[9].

Now, taking the total derivative of the QDE (1), gives us a line in a yield-soil-diagram, an isocline (2) as depictured in diagram 1.

(2) $$\dot{B} = 0 \Rightarrow \frac{\partial f(y,B)}{\partial y} dy + \frac{\partial f(y,B)}{\partial B} d\,B = 0 \quad \Rightarrow \quad \frac{dy}{dB} = -\frac{\partial f(y,B)/\partial B}{\partial f(y,B)/\partial y} = -\frac{f_B}{f_y} > 0$$

Within our model we omit to specify the functional form of (1) and therefore the curvature of (2) is also not specified[10]. Nevertheless, the partial derivatives of *f* determine the direction of the arrows in diagram 1. The relevant aspect here is, that $\dot{B} = 0$ indicates the border of the ecological viability.

Diagram 1: soil productivity development areas



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2.2 The economical part

Profit per ha, π, consists of revenue per ha (i.e. price times crop per ha) net of production costs[11]. Production costs depend on crop per ha as well as on soil productivity:

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[8] Impovement ist possible as in the Sahara Syndrome Model (EISENACK, 2005, PETSCHEL-HELD ET AL., 1999a) and EuroGeoSurveys, 2005, as well as LFL, 2003. Improvement has to be distinguished from formation, which is beyond human horizon (STMUGV, 2006a). Improvement is feasible in case of compression, not erosion (STMUGV, 2006a).

[9] As in the Sahara Syndrome Model (EISENACK, 2005, PETSCHEL-HELD ET AL., 1999a).

[10] But additional assumptions are 1. an upper limit B_{max} for soil productivity, and 2. an upper limit y_{max} for crop per ha. Last but not least, the independence of y_{max} from soil productivity serves for simplification of the diagrams and can be released without effects on the results.

[11] It takes the rule of the Poverty equation in the Sahara Model (EISENACK, 2005, PETSCHEL-HELD ET AL., 1999a).

(3) $c = \text{costs}/ha = c(\underset{(+)}{y},\underset{(-)}{B})$

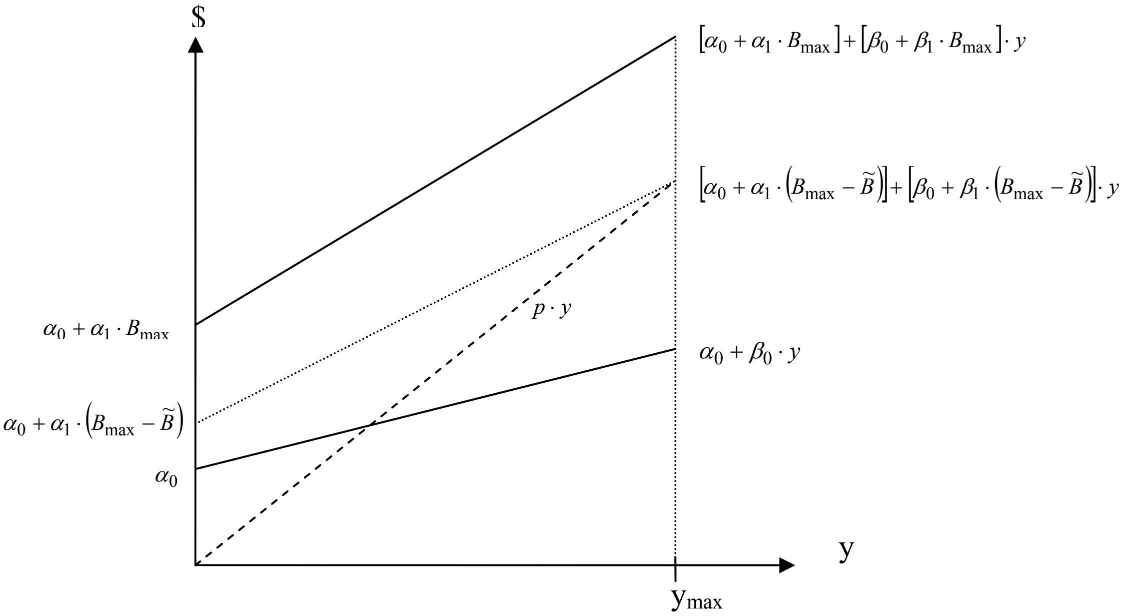
We will assume that production costs act upon the following formula:

(4) $c(y,B) = [\alpha_0 + \alpha_1 \cdot (B_{\max} - B)] + [\beta_0 + \beta_1 \cdot (B_{\max} - B)] \cdot y$ with $\alpha_0, \alpha_1, \beta_0, \beta_1 > 0$

The first term represents fixed costs of machinery, buildings, overhead-costs etc. – divided by agricultural area. Thus, even the most productive soil B_{max} accounts for some fixed costs per ha, α_0. Furthermore, the less productive the soil (lower B), the more special equipment has to be available (LFL, 2003), resulting in a higher fixed costs term. Additionally, less productive soil asks for special work to yield the same output as more productive soil (LFL, 2002, LFL, 2003). Hence variable production costs are higher on less productive soil[12]. But, as the production requires seed and harvest anyway, even for the most productive soil, variable production costs never diminish.

The cost structure is explained through the two limiting, drawn through cost curves in the following diagram. The upper cost curve relates to least productive soil and the lower cost curve with the small axis intercept and low variable production costs corresponds to most productive soil.

Diagram 2: revenue and production costs per ha as function of yield per ha



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Therefore, profit per ha is $\pi = p \cdot y - c(y,B)$, and as losses are unfavourable, π should stay non-negative, i.e. $\pi_{min} = 0$. Again, taking the total derivative of π_{min}, gives us another element in the yield-soil-diagram:

(5) $\pi_{\min} = 0 \Rightarrow p \cdot y - c(y,B) = 0 \Rightarrow p \cdot dy - \frac{\partial c}{\partial y} dy - \frac{\partial c}{\partial B} dB = 0 \Rightarrow \frac{dy}{dB} = \frac{\partial c / \partial B}{p - \partial c / \partial y} \square\, 0$

[12] E.g. additional fertilizer substitutes for a health soil structure (LFL, 2003).

In the specified case of the production costs function from above, we have:

(6) $$\frac{\partial c(y,B)}{\partial y} = [\beta_0 + \beta_1 \cdot (B_{\max} - B)]$$

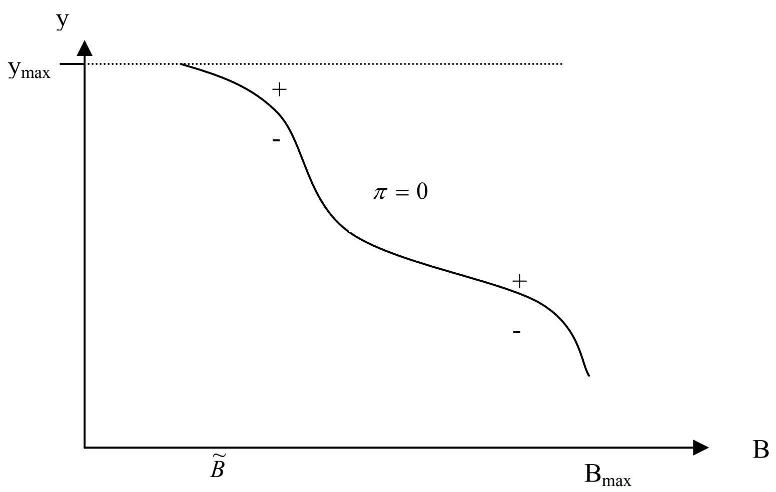
and even for the least productive soil, i.e. for the soil type with the highest variable production costs, we assume:

(7) $$p > \partial c/\partial y \Rightarrow \frac{d\,y}{d\,B} = \frac{\partial c/\partial B}{p - \partial c/\partial y} < 0\,.$$

Graphically this assumption suggests that for all type of soil, the revenue curve is steeper than the cost curve, as depictured in the diagram above by the dashed curve.

In case even the least productive soil type relates to a break-even y (i.e., we would assume a steeper revenue curve in the diagram above which crosses the upper cost curve), in the yield-soil-diagram the zero-profit-line would become a strictly monotonic decreasing curve ab initio. Contrary, in case low productive soil cannot earn money, as depictured in the diagram above, there is no zero-profit-line as long as losses are unavoidable due to soil deficits, and thenceforward the zero-profit line decreases monotonically as displayed in the following diagram. Soil types, which are unable to earn money, are assumed to be abandoned from agricultural production.[13] Therefore, the $\pi = 0$-line starts at level y_{max} and represents "the higher the soil productivity, the lower yield necessary to break even".

Diagram 3: zero profit line



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Above the $\pi = 0$-line, we observe profits as more crop is produced than necessary to "break even", and below the $\pi = 0$-line we observe losses. The +- and –sign in the diagram above indicate this relationship. The location of the $\pi = 0$-line depends on the price p as well as on the cost parameters[14]. Higher values of p shift the $\pi = 0$-line to the left, higher cost parameters to the right.

[13] Due to the assumption (7), break even is realised at y_{max} for the economical limiting $\tilde{B}$.

[14] For the linear costs structure, the form of the $\pi = 0$-curve can be specified. But as this fact is not essential for the results of qualitative analysis, we generalise to any decreasing line and draw a straight line further on.

We assume that ecological changes are slow-going compared to feasible economical adjustments. To keep analysis easy, we put back the involvement of time-effects of projected yield adjustments. But we model the situation as follows: farmers control the system via adjustments of crop per ha. They do not directly choose crop per hectare, but whether it increases or decreases (and how much it will in- or decrease) compared to the current level. Our assumption of unbounded crop adjustments implies evolutions can jump parallel to the y-axis.

Here, we have to add two comments: first, the $\pi = 0$-line indicates the border for economic viability; second, it does not correspond to the profit maximizing output.

As we focus on the economic viability, and have a limit crop per ha, the area below y_{max}, but above the $\pi = 0$-line, contents evolutions fulfilling the economic constraint. It is denoted by K.

The next step is to ask whether there does exist at least one control (adjustment rule for crop per ha) such that the future stays viable, i.e. does not leave K, forever. The answer will be given in chapter 2.3.

2.3 Viability kernel

The Viability kernel contains initial (soil, yield)-combinations, for which at least one evolution can ensure viability forever. Mathematically,

(8) $$Viab(K) = \{(B_0, y_0) \in K \mid \exists (B, y)(\bullet) \in S, \forall t > 0, (B, y)(t) \in K\}$$ with:

S = set of evolutions starting in the initial state

The situation marked with an asterisk in Diagram 4 is at the border of viability in the long run due to the position above the intersection of the $\dot{B} = 0$-isocline with the $\pi = 0$-line. The Viability kernel contains initial states for which at least one evolution can ensure viability forever. The area above the $\pi = 0$-line, but right hand side of the intersection with the $\dot{B} = 0$-isocline is the Viability kernel. All initial situations in the Viability kernel allow for a crop per ha adjustment which conserves soil productivity forever and, at the same time, guarantees profits per ha. On the other hand, the remaining part of K (left hand to the intersection and above the $\pi = 0$-line) misses any evolution conserving soil productivity without a crisis time and losses per ha. Therefore, K\Viab(K) strongly asks for a CAP Improvement[15,16,17].

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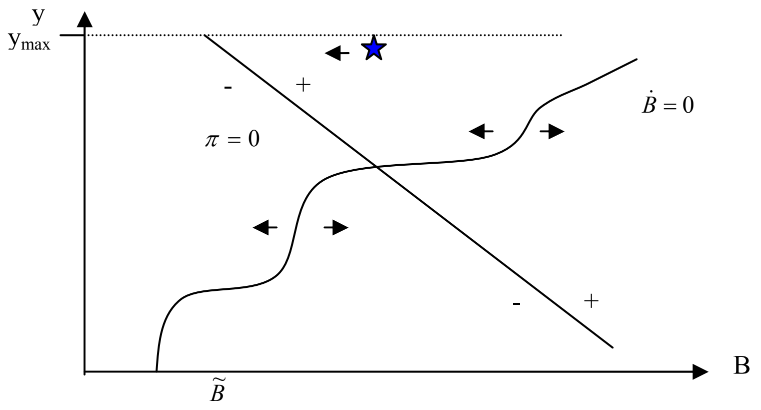
[15] But even though Viab(K) ≠∅ in the diagrams depictured in this paper, as we observe $y = y_{max}$ in general, Viab(K) is at risk to leave K in the long run, too.

[16] Most agricultural land in the EU is still fare away form leaving viability; i.e. to reach the border will still take a lot of time – even with $y=y_{max}$. But there exist areas deforested some thousand years ago, and misused in the past decades which tend to develop into deserts. Parts of central Spain can be mentioned in this context. Rainfall level is traditionally low, but it is not long since irrigation water become scare, too. Albeit, agricultural production remains on a high level – presumably as long as possible.

[17] An example from European past recording a story of soil degradation is the history of Island, where soil degradation followed the settlement by the Vikings, and survival required massive changes in agricultural practice (DIAMOND, 2006).

Diagram 4: viability kernel



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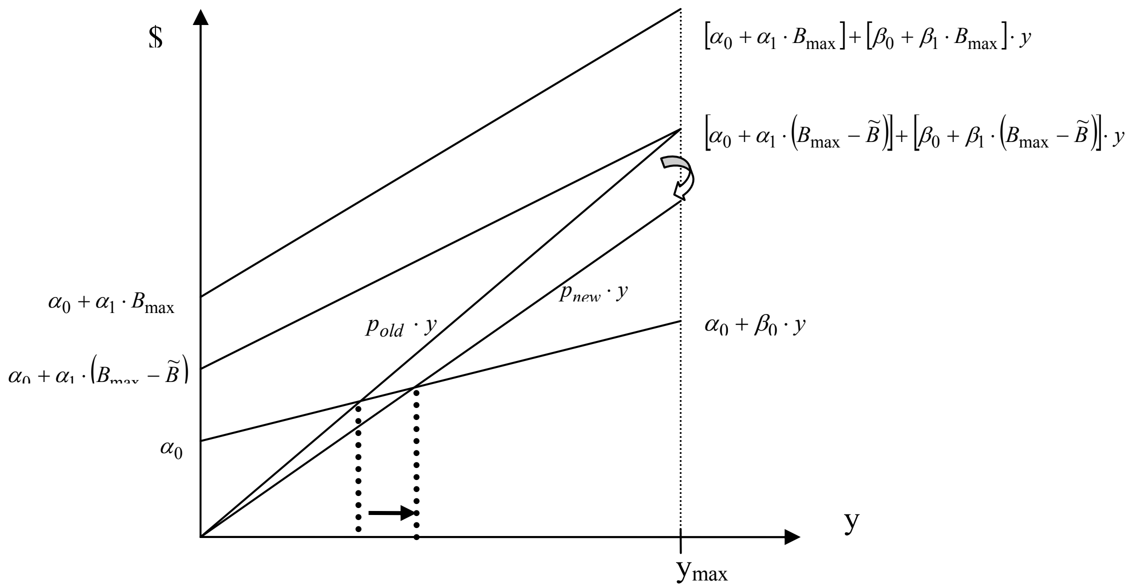
3 Viability due to the new policy?

Within the mid term review CC was introduced. To fulfil CC requirements is a precondition to activate entitlements. They compensate for abandoned direct payments and for reduced price support. Additionally, agri-environmental programs exist with compensating payments and an obligation to farm environmentally sustainable. In total, three aspects should be considered to analyse the new policy: 1. induced reduction in agricultural prices; 2. entitlements, and 3. requirements to activate the payment related to entitlements.

Diagram 5: reduced price support



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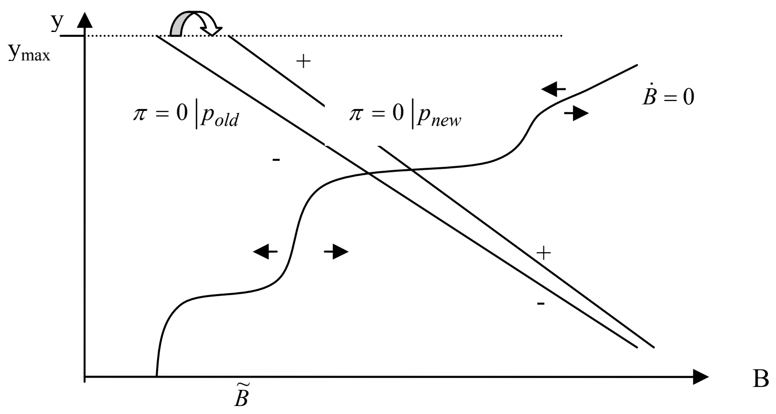
The first and the second issue influence the $\pi = 0$-line. The third issue requires a realization on the $\dot{B} = 0$-isocline. It will be analysed last. First, we look at reduced price support. As the price decreases, the revenue curve twists downward (see Diagram 5). The induced effect on $\pi = 0$-line in the yield-soil-diagram (see Diagram 6) is an upward move as now higher output per ha is necessary to break even. The lower soil productivity, the larger the effect.

Diagram 6: change in the $\pi = 0$-line



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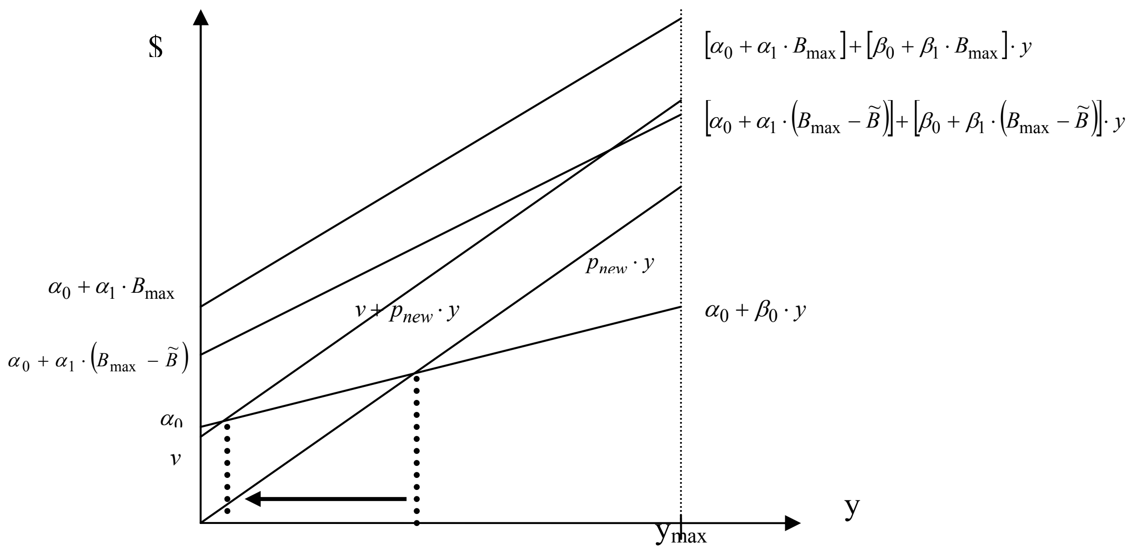
Next, farmers have the opportunity to activate an entitlement *v* per ha[18] (see Diagrams 7).

Diagram 7: entitlement *v*



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Due to *v* we see a parallel shift in revenue, effecting break even *y* on less productive soil stronger than on more productive soil.

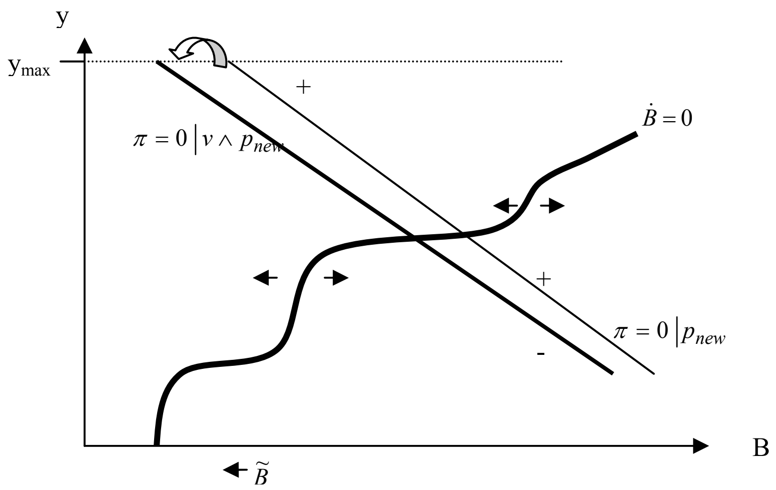
Finally, CC-soil conservation and the obligations from adequate agri-environmenatl programs are thought to correspond to place on the $\dot{B} = 0$-isocline (see Diagram 8[19]).

[18] Currently the nominal amount of an entitlement results from a regional average (differentiated by the type of entitlement (arable farm land, grassland, etc.)) and from a farm-individual component. To keep analysis easy, we abstract from regional-, type-, and individual differences in the nominal amount of entitlements and assume, that a uniform *v* exists, which compensates at least for costs of mulching but not necessarily for the fixed costs on production.

[19] For example, farmers are asked to mulch and cultivate intertillage and to utilize other comparable measures, in order to conserve soil productivity. They are not tied to specific devices for seeding, cultivation or harvesting. Insofar, there remains a certain freedom in the choice of technology.

In connection to direct payments, the law binds farmers to omit soil erosion, further to protect soil structure and landscape elements and to take care of set aside acreage (BUNDESGESETZBLATT, 2004). In case of non-compliance they have to prove farm sustainability through yearly humus balance sheets and documented monitoring of humus content.

Diagram 8: Cross compliance



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The model states, signing CC contracts or participating in adequate agri-environmental programs ensures a future development in the Viability kernel in case the present belongs to the Viability kernel. The new instruments of CAP might have enlarged the kernel, and therefore introduced an opportunity for viable evolutions. Whether they enlarged the kernel or not, depends on whether the intersection of the new $\pi = 0$-line with the $\dot{B} = 0$-isocline is left hand or right hand from the intersection of the former $\pi = 0$-line with the $\dot{B} = 0$-isocline.

But whether farmers chose to oblige to CC or adequate agri-environmental programs depends on the relative profitability of entitlements compared to forgone profits due to being tied to the $\dot{B} = 0$-isocline. In the diagram above, none would vote for entitlements & CC. But in case that 1. the $\dot{B} = 0$-isocline starts with an y-axis intersection, is flat and hits the y_{max} line, and 2. the difference between $\pi = 0$-line with and without entitlement is large, different soil productivity types would devote for the new combination of entitlements & CC or an adequate agri-environmental program. Interestingly, those who vote for participating at the program might not necessarily be represented by a closed range of soil productivity. To see the issue, look at decreasing soil productivity. On the one hand, lower soil productivity increases the losses due to being tied to the $\dot{B} = 0$-isocline, but on the other hand, the profitability of the entitlement also increases. Which one of the effects outweighs the other, is a priori open.

4 Results

Our paper focused on conservation measures for agricultural crop land in order to keep it in good agricultural and ecological condition. These measures are an element of obligations within CC (according to attach IV of the decree (EG) Nr. 1782/2003) and in adequate agri-environmental programs.

As the model demonstrated, without any rules farmers will not preserve soil productivity in the long run. But through attachment of conservation measures and financial support, some farmers have an incentive to keep the evolution viable. With some information about position and curvature of the $\dot{B} = 0$-isocline, the acceptance of CC contracts or the participation in an adequate agri-environmental program can be forecasted and further improvements for policy instruments developed.

5 Extensions

Viability theory usually handles uncertainty within the development of the ecological system. Soil development to a relevant part depends on weather and climatic conditions. Nowadays, extreme weather conditions occur more often than a quarter of a century ago, and a durable climate change is expected, but its size is open. Therefore, an extension introducing volatility and a trend in the $\dot{B}=0$-isocline is thinkable[20].

More, forecasts for price development are very unequal. And the volatility in prices for agricultural products might further increase. This aspect effects the position of the $\pi=0$-line. The $\pi=0$-line can fluctuate within a certain range[21]. The uncertainty factors altogether might depend on each other. Nevertheless, the viability of the evolution becomes a random variable; to analyse its distribution is an interesting task.

Last but not least, Viability theory deals with crisis time. A promising aspect is to analyze the time span and size of public expenditures necessary to bring back soil in bad condition to the Viability kernel. Such an analysis could be extended through the addition of a defined European target and the identification of the corresponding capture basin.

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