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EXIOPOL

A NEW ENVIRONMENTAL ACCOUNTING FRAMEWORK USING EXTERNALITY DATA AND INPUT-OUTPUT TOOLS FOR POLICY ANALYSIS

REVIEW REPORT ON THE LITERATURE THAT LINKS ENVIRONMENTAL AND ECONOMIC THRESHOLD EFFECTS

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Justus Wesseler, editor

Wageningen University, Environmental Economics and Natural Resources

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Preamble

Environmental pressures often result in discontinuities in the valuation function characterized ecosystems abruptly change from one stable state of nature to another one. Examples include the eutrophication of lakes, coral reef ecosystems or the Sahel region (Scheffer et al., 2001; Scheffer and Carpenter 2003). Often the change from one to another stable state of nature is not desired as moving back is either irreversible or causes hysteresis[1]. Scheffer et al. (2001) conclude in their review catastrophic shifts in ecosystems require environmental policies that strengthen the resilience of ecosystems.

The problem of shifts from one stable state of nature to another stable state of nature is very familiar to environmental and natural resource economists. In the literature on cost-benefit analysis economists try to identify the threshold value for moving from non-investment, one stable state of nature, to investment another stable state of nature or from investment to disinvestment. Investment is understood as implementing a project or synonymously a policy in its broadest sense. Examples include the development of a nature conservation area for oil drilling or residential purposes, construction of a road though a protected area, or investment in nature conservation but also investments in SO_2 emission reduction and carbon sequestration or regulatory policies such as banning the use of certain chemicals or pesticides.

Important aspects to consider include irreversibility, uncertainty and flexibility on the threshold level for implementing the project. External effects can either increase or decrease the threshold level from a social perspective. The effect on the threshold level depends on whether or not those external effects are reversible or irreversible and positive or negative. From a decision makers point of view it will also be important to know to what extend benefits and costs occur are at the private or public sector level.

While a number of models have been developed for economic variables and their impact on threshold values, models including ecological variables are less prominent. In this contribution merging ecological and economic models of regime shifts will be reviewed.

First, the standard economic model will be introduced and the properties discussed. This is followed by including a standard ecological model illustrating the interrelationship between ecological and economic threshold values. One of the most interesting insights perhaps is that the size of the ecological threshold values increases the size of the economic threshold values and that ecological uncertainty alone can cause economic hysteresis.

Coordinator of Work Package II.1.c

EXIOPOL project

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[1] For a review of the terminology consult the FP6 thresholds project: http://www.thresholds-eu.org/

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1 The standard economic model

The decision whether or not to implement a project is one subject to uncertainty and irreversibility. This has been recognized by economists (Arrow and Fisher, 1974; Henry, 1974). Uncertainty related to the implementation of a project exists with regard to the future benefits of the project as in general future benefits and costs are not known with certainty due to several factors including environmental factors such as climate change at micro and macro level and future policies and technical change changing relative prices of future benefits and costs.

Irreversible effects of a project include effects on: human health, due to changes in emissions; biodiversity; climate change, due to changes in greenhouse gas emissions; sunk costs and; administrative costs due to new regulations.

The effects of irreversibilities on the value of a project, be it an investment by a single investor or a project financed by the government, were analyzed in the seminal papers of Kenneth Arrow and Anthony Fisher (1974) and Claude Henry (1974). The basic result is that if one considers a project with uncertain costs and benefits, irreversible costs and the possibility to postpone the investment (flexibility), then the investment should only be undertaken immediately if the benefits exceed the costs by a certain amount and not if they are equal to or greater than the costs as the standard net-present-value rule suggests. The amount by which the benefits have to exceed the costs under uncertainty, irreversibility, and flexibility has been called the quasi option value. The quasi option value can be explained by the gains from waiting due to the arrival of new information over time. The concept of the quasi option value is similar to the real option value. The real option value originated from financial economics. In the literature on real option valuations, the opportunity to invest is valued in analogy to a call option in financial markets. Investors have the right but not the obligation to exercise their investments. This right, the option to invest (real option) has a value, which is a result of the option owner's flexibility. Chavas (1994) provided similar results in his application to investments in agriculture. Dixit and Pindyck (1994) suggest an application of the real option approach not only to investment problems but to all kinds of decision making under temporal uncertainty and irreversibility.[2] The approach has been applied to a number problems, among others, regime shifts of ecosystems (Freeman and Zeitouni, 2004), climate change policies (Pindyck, 2000) the adoption of soil conservation measures (Winter-Nelson and Amegbetto 1998; Shively 2000), wilderness preservation (Conrad 2000); forest conservation (Rahim et al., 2007), agricultural labor migration (Richards and Patterson 1998) and investment in irrigation technology (Carey and Zilberman, 2002) to name only a few. Applications related to agricultural biotechnology include studies by Kikulwe et al. (2007); Wesseler et al. (2007); Demont et al. (2004), Knudsen and Scandizzo (2004) and Morel et al. (2003) and Wesseler (2003). Leitzel and Weisman (1999) apply the real option approach to the analysis of government reforms and argue that new government policies require investments in the form of training of government officials, hiring of additional workers, and purchase of equipment. A part of these costs is irreversible and the success of the implemented policy is uncertain, which results under flexibility in a positive value of the option to delay the implementation of the policy.

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[2] Nobel laureate Robert C. Merton (1998) provides an overview of the application of the option pricing theory outside financial economics. The book by Amram and Kulatilaka (1999) includes several case studies of real option pricing. The special issue on irreversibilities of the journal Resource and Energy Economics, Volume 22 (2000) includes application in the field of environmental and natural resource economics.

2 Decision in the presence of irreversible costs

Consider the effects of irreversibility, uncertainty and flexibility in the context of a development project. Consider a decision maker who wants to implement a project. The implementation of the project includes sunk costs. The current net-benefit without the project is about 1000 units. The net-benefit including the is expected to be about 1200 units. The expected incremental net-benefit is 200 units per year received at the end of the year. The example will be kept simple by assuming the incremental benefits are certain and will remain constant forever. The discount rate is 10%. The value *V* of implementing the project in this case is simply the present value of the infinite incremental net- benefit stream, $V = \sum_{t=1}^{t=\infty} 200 \cdot (1.1)^{-t} = \frac{200}{0.1} = 2000$. For the decision to implement the project the sunk costs have to be deducted. The sunk costs *I* are 1600 Euros. The net-present-value, *NPV*, of the development project is *NPV* = *V* – *I* = 2000 – 1600 = 400. The *NPV* is positive and it can be concluded implementing the project is a sensible decision.

Introducing risk about the future incremental benefits may change the results. Assume the future incremental net-benefits can either be high at 300 units or low at 100 units. The decision maker will only know after one year whether or not the the incremental benefits will be high or low. Both situations are equally likely and occur with a probability of q=1-q=0.5. As by assumption the decision maker is risk neutral, he would implement project if the expected present value of the project is positive. The expect value, *E[V]*, of the project ignoring the availability of future information is the sum of the probability weighted two states of nature:

1. $$E[V] = 0.5 \cdot \sum_{t=1}^{t=\infty} 300 \cdot (1.1)^{-t} + 0.5 \cdot \sum_{t=1}^{t=\infty} 100 \cdot (1.1)^{-t} = 2000 .$$

The result is the same as before. Deducting the initial sunk costs of 1600 units results in an NPV of 400 as before.

In case the future benefits are low, $V_0 = \sum_{t=1}^{t=\infty} 100 \cdot (1.1)^{-t} = 1000$ the value of the project does not cover the sunk costs of 1600 units. This would not be a problem if the decision maker could easily remove back to the initial state and recover the sunk costs. In this case the development project would be reversible.

In almost all cases it would be difficult to fully recover the sunk costs. In the case the decision maker is unable to recover a part of the sunk costs the investment costs are totally irreversible. This is similar to the effect of hysteresis as mentioned by Scheffer et al. (2001).

Now, assume the decision maker is flexible and can postpone his decision. In the case the incremental benefits increase, the *NPV* of the development project one year from now is:

$NPV_1 = -1600 + \sum_{t=2}^{t=\infty} 300 \cdot (1.1)^{-t} = 1400$ or in today's value $NPV_0 = NPV_1 / 1.1 = 1273.$ In case the incremental benefits decrease, the *NPV* of the development project one year from now is:

$NPV_1 = -1600 + \sum_{t=2}^{t=\infty} 100 \cdot (1.1)^{-t} = -600$ or in today's value $NPV_0 = NPV_1 / 1.1 = -545.$ In the latter case the decision maker would better of not implementing the project.

The decision maker can gain from waiting to implement the project. The gain from waiting is the gain from avoiding losses of 545 units in present value. The economic gain from waiting can be calculated by comparing the expected $E\left[NPV_0^I\right]$ of the immediate investment with the $E\left[NPV_0^P\right]$ from waiting one year. The $E\left[NPV_0^I\right]$ from immediate investment is 400 Euro. The $E\left[NPV_0^P\right]$ is:

2. $$E\left[NPV_0^P\right] = \left[0.5 \cdot \left(-1600 + \sum_{t=2}^{t=\infty} 300 \cdot (1.1)^{-t}\right) + 0.5 \cdot (0)\right] \Big/ 1.1 = 636 .$$

The $E\left[NPV_0^P\right]$= 636 and is greater than the $E\left[NPV_0^I\right]$ of 400 units from immediate development. In this case it would be worthwhile waiting. The economic gain from waiting is the difference between the two, i.e. 236 units.

At this point it is worthwhile noting the importance of the irreversibility effect. It only pays to wait when the initial development costs are irreversible. This observation will be even more obvious if the incremental net-benefit would be negative in the bad case.

If the initial development costs were not irreversible, immediate development would be optimal. Also, it would be optimal to develop immediately, if the decision could not be postponed due to other circumstances.

A third important observation is the opportunity costs of waiting. Waiting pays as the veil of uncertainty will be removed after one year, but at the same time the benefits at the end of year one are foregone. These foregone benefits of expected 200 units are the opportunity costs of waiting.

2.1 Decision in the presence of irreversible costs and irreversible benefits

As there are irreversible costs there might also be irreversible benefits (e.g. Wesseler, 2009; Pindyck, 2000; Kolstad, 1996; Ulph and Ulph, 1997). These are benefits that will continue to be present even if the action that has produced them stops. Consider, for example, a one-time irreversible benefit of 500 units from implementing the project.

There are other examples that will be discussed in more detail later. The $E\left[NPV_0^I\right]$ increases in this case by exactly 500 units and the $E\left[NPV_0^I\right]$ = 900. The $E\left[NPV_0^P\right]$ from waiting in this case is:

3. $$E\left[NPV_0^P\right] = \left[0.5\cdot\left(-1600+500+\sum_{t=2}^{t=\infty}300\cdot(1.1)^{-t}\right)+0.5\cdot(0)\right]\Big/1.1=864 .$$

The $E\left[NPV_0^I\right] > E\left[NPV_0^P\right]$ and there are no gains from waiting. The irreversible benefits reduce the irreversible cost, which results in this case in immediate development to be optimal.

Now, consider the case, where the previously assumed irreversible benefits only last for ten years. In this case do the benefits matter? The $E\left[NPV_0^I\right]$ of immediate development where the additional last only for ten years provides the following result:

4. $$E\left[NPV_0^I\right] = -1600+500-\frac{500}{1.1^{10}}+0.5\cdot\left[\sum_{t=1}^{t=\infty}300\cdot(1.1)^{-t}+\sum_{t=1}^{t=\infty}100\cdot(1.1)^{-t}\right]=707 .$$

The $E\left[NPV_0^I\right]$ of immediate development in this case is 707 units, which is higher than in the case without (400 units) and less than in the case of irreversible benefits (900 units).

The result for a postponed development is the following:

5. $$E\left[NPV_0^P\right] = \left[0.5\cdot\left(-1600+500-\frac{500}{1.1^{10}}+\sum_{t=2}^{t=\infty}300\cdot(1.1)^{-t}\right)+0.5\cdot(0)\right]\Big/1.1=776 .$$

The $E\left[NPV_0^P\right]$ from immediate development in this case is 775 units, which is also in this case higher than in the case without (636 units) and less than in the case with a temporary effect (864 units). We further observe, that the optimal decision will be to postpone the development, wait for one year and develop if the incremental benefits increase and do not if they decrease. Again, there are positive gains from waiting.

2.2 Decision in the Presence of Irreversible Benefits

Another interesting question related to the irreversible benefits is, whether there are gains from waiting if only irreversible benefits and no irreversible costs are present or if the net-irreversibility effect is positive. Under a positive net-irreversibility effect there will be no gains from waiting, as there are no losses that can be avoided. The $E\left[NPV_0^I\right]$ in the case of irreversible benefits only is

6. $$E\left[NPV_0^I\right] = 500 + 0.5 \cdot \sum_{t=1}^{t=\infty} 300 \cdot (1.1)^{-t} + 0.5 \cdot \sum_{t=1}^{t=\infty} 100 \cdot (1.1)^{-t} = 2500$$

and in the case of the postponed development:

7. $$E\left[NPV_0^P\right] = 0.5\left[500 + \sum_{t=2}^{t=\infty} 300 \cdot (1.1)^{-t} + 500 + \sum_{t=2}^{t=\infty} 100 \cdot (1.1)^{-t}\right] \Big/ 1.1 = 2273$$.

The $E\left[NPV_0^I\right]$ under this scenario will always be greater than the $E\left[NPV_0^P\right]$ due to the discounting effect and therefore waiting does not provide an economic gain.

The important observations about the irreversible benefits are threefold. First, irreversible benefits reduce irreversible costs and this by the order of one. One unit of irreversible benefits compensates for one unit of irreversible costs. Second, a decrease in irreversible benefits over time, even up to a hundred percent, still has a positive impact on the value of the project. Third, a positive irreversibility effect does not provide economic gains from waiting. A more detailed exposition on this point can be found in Wesseler (2009).

2.3 The Special Case of Pest-Resistance

An interesting effect to analyze in more detail is the possibility of pest resistance. The susceptibility of pests to control agents has been viewed by economists as a non-renewable resource, and hence the appearance of pest resistance as an irreversibility. Biologists and entomologists in particular argue that susceptibility to control agents, pesticides in particular, should be viewed as a renewable resource. That is, if pests become resistant to a control agent and consequently the use of the control agent stops, pest resistance breaks down after a while and pests do become susceptible again. The important question within the context of this paper is whether or not an irreversibility effect exists. To show that an irreversibility effect does indeed exist consider the following hypothetical example for Bt-corn used against damages from the European Corn Borer (ECB). The incremental benefits from adopting Bt-corn are assumed to be 200 at the beginning, period one, and due to price uncertainty increase to either 300 or 100 after one time period and remain at the level till the end of the fourth period. At the end of the fourth period the ECB becomes resistant to Bt-corn and the incremental benefits decrease to zero from period five till the end of period seven. At the end of period seven, the ECB becomes susceptible again to Bt-corn. To keep the example simple, we assume that the incremental benefits increase to 200 Euro until infinity as the ECB will also be susceptible till infinity. The example is illustrated in figure 1. The costs of pest resistance in present value terms are 1600 Euro. These are extra costs beyond the lost incremental benefits of period five, six and seven.

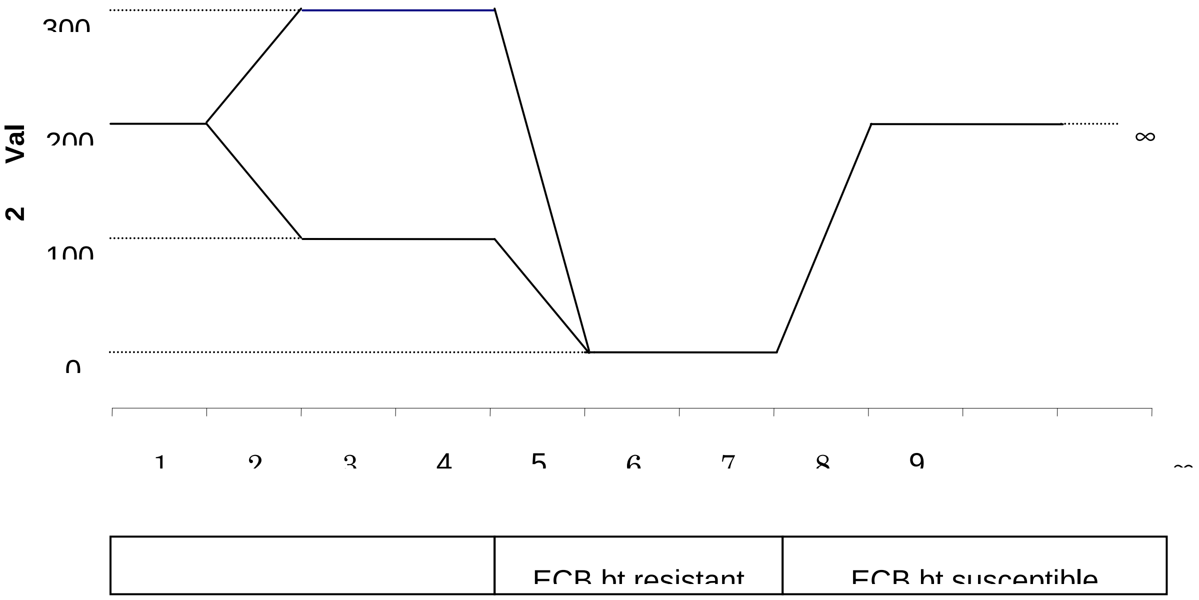

Figure 1: Example for appearance and breakdown of ECB resistance to Bt-toxin.

The value of Bt-corn from immediate adoption is:

$$8.\quad E\left[NPV_0^I\right] = -1600 + 200 \cdot 1.1^{-1} + 0.5 \cdot \sum_{t=2}^{t=4} 300 \cdot (1.1)^{-t} + 0.5 \cdot \sum_{t=2}^{t=4} 100 \cdot (1.1)^{-t} + \sum_{t=8}^{t=\infty} 200 \cdot (1.10)^{-t} \cong 60$$

The result for a postponed adoption is

$$9.\quad E\left[NPV_0^P\right] = \left[0.5 \cdot \left(\frac{-1600}{1.1} + \sum_{t=2}^{t=5} 300 \cdot (1.1)^{-t} + \sum_{t=9}^{t=\infty} 200 \cdot (1.1)^{-t}\right)\right] \cong 171 \cdot$$

The above example illustrates that even though pest resistance can be reversible from a biological point of view, from an economic point of view an irreversibility effect may exist.

All the examples that have been discussed were constructed in a way that it was always optimal from an economic point of view to delay the adoption of transgenic crops. What is important to note is that while an irreversibility effect exists, it will not always be optimal to postpone the adoption. In cases where the irreversible costs are small or the incremental benefits are high, immediate adoption can be optimal.

3 Private and Public Irreversibilities

In the example we did not differentiate between irreversible benefits and costs. For the assessment of benefits and costs of transgenic crops and for the decision whether or not to release them, a distinction between private and social benefits and costs of transgenic crops has to be made. Private costs and benefits are important for the analysis of the adoption potential among farmers. This will provide information about the expected aggregated private net-benefits from introduction. In addition, external benefits and costs have to be considered. These include, among others, climate change effects, impacts on biodiversity and impacts on farmers' health. Further, the examples of the previous chapter illustrate the necessity of a differentiation between reversible and irreversible costs and benefits. A two-dimensional matrix (or three-dimensional one, if benefits and costs are added as an additional dimension) can be designed considering these differentiations for an ex-ante social cost-benefit analysis of transgenic crops as depicted in Figure 2. A complete ex-ante analysis of economic benefits and costs of transgenic crops should consider all four quadrants of figure 2.

Scope Reversibility	Private	External
Reversible	**Quadrant 1** Private Reversible Benefits (*PRB*) Private Reversible Costs (*PRC*)	**Quadrant 2** External Reversible Benefits (*ERB*) External Reversible Costs (*ERC*)
Irreversible	**Quadrant 3** Private Irreversible Benefits (*PIB*) Private Irreversible Costs (*PIC*)	**Quadrant 4** External Irreversible Benefits (*EIB*) External Irreversible Costs (*EIC*)

Figure 2: The Two Dimensions of an Ex-Ante Social Benefit-Cost Analysis of a Project

As an example we use an ex-ante assessment of herbicide tolerant sugar beets (htSB) in Europe as explained in detail in Demont et al. (2004). The decision rule to release htSB is formulated as, to release htSB if the net reversible social benefits W, the sum of quadrant 1 and quadrant 2 in figure 2, are greater than the net irreversible costs, the sum of quadrant 3 and quadrant 4, multiplied by a factor greater than one, the so-called hurdle rate η:

10. $$W \geq (I - R) \cdot \eta \text{ .}$$

As the social irreversible costs, $I=PIC + EIC$, and benefits, $R=PIB+EIB$, of transgenic crops are highly uncertain, instead of identifying the net reversible social benefits W required to release transgenic crops in the environment, the maximum tolerable social irreversible costs I^* under given net social reversible benefits W and social irreversible benefits R are identified:

11. $I^* = R + W/\eta$.

In Table 1 the results are presented. The estimated hurdle rates are entirely coherent with the expectations. We observe a bimodal distribution. Low cost sugar beet producers such as France, Belgium, the Netherlands, Germany, Denmark, the UK, and Italy have low hurdle rates (1.25-1.82), while high cost areas like Spain, Ireland, Austria, Sweden, Greece, and Finland have higher ones (2.10-3.69), requiring higher values of W to justify a release of HT sugar beet.

The values of W, R, and I^* are presented as annuities of an infinite and continuous stream of benefits respectively costs per hectare planted to transgenic sugar beet. W ranges from 121 Euro to 354 Euro with an average of 199 Euro per hectare. High cost areas generally have high values for W, which can be explained by the EU sugar policy. Except a few outliers, estimates for R are low and range from 0.18 Euro to 3.36 Euro with an average of 1.59 Euro per hectare. This is due to the fact that we use conservative estimates from literature for the average external social cost of pesticide application. The maximum tolerable social irreversible costs range from 50 Euro to 212 Euro per hectare, i.e. in the range of 27-80% of the annual net private reversible benefits. For the EU as a whole this means that it should accept transgenic sugar beets as long as social irreversible costs do not exceed 121 Euro per hectare, totalling 103 Mio. Euro per year. There is a large divergence between estimates for R and I^*. For the EU e.g., I^* is 76 times larger than R. The social irreversible benefits R include impact of pesticide use on the environment, biodiversity and climate. As the social irreversible costs I^* include the same environmental effects, it is hard to believe that they are higher by a factor of 76. The total net private reversible benefits forgone, W, if the *de facto* moratorium is not lifted are in the order of 169 Mio. Euro per year.

On the other hand, the social reversible net benefits plus the social irreversible benefits are about one Euro per household in the EU only. If households put a value on the potential irreversible costs of transgenic crops of one Euro or more, than the ex-ante net social benefits of htSB are negative and htSB should not be released.

Table 1: Hurdle Rates and Annual Net Private Reversible Benefits (*W*), Social Irreversible Benefits (*R*), and Maximum Tolerable Social Irreversible Costs (*I) per Hectare Transgenic Sugar Beet**

Member State	*W* (□/ha)	*R* (□/ha)	Hurdle Rate	*I** (□/ha)	Total *I** (□)
Austria	251	3.36	2.88	91	1,842,164
Belgium & Luxembourg	168	2.09	1.26	135	5,852,023
Denmark	178	2.06	1.73	105	2,864,870
Finland	251	0.74	3.69	69	976,108
France	179	1.05	1.25	145	24,964,742
Germany	179	1.57	1.36	134	27,846,376
Greece	264	7.97[b]	3.12	93	1,771,502
Ireland	116	-0.96[b]	2.29	50	691,951
Italy	330	2.32	1.82	183	22,682,730
The Netherlands	121	0.83	1.31	94	4,630,433
Portugal	354	-0.65[b]	1.67[c]	212	615,218
Spain	252	0.53	2.10	121	7,258,219
Sweden	150	0.18	3.01	50	1,226,127
UK	127	1.78	1.76	74	5,135,522
EU	**199**	**1.59**	**1.67[a]**	**121**	**102,628,681**

[a] sugar beet area-weighted average of the individual Member States' hurdle rates.

[b] The extreme estimates for Greece, Ireland and Portugal are probably due to data inconsistencies. These countries only cover 4% of total EU sugar beet area, almost not affecting the EU average.

[c] No data on margins has been found for Portugal. We use the EU area-weighted average.

Source: Demont et al., 2004.

4 Discussion

The simple numerical examples present demonstrate irreversibilities in combination with uncertainty and flexibility do have an effect on threshold values for the decision whether or not to implement a project immediately. Hysteresis which causes an irreversibility effect causes the threshold levels to be higher than otherwise. Ecologists have provided a number of examples where drastic changes in ecosystems cause systems from one state to another state. Those drastic shifts do occur if certain threshold levels will be reached. The regime shift is that drastic the ecosystems will not be able without any intervention to move back to the previous state. Often those drastic regime shifts are not desired by society. To prevent the drastic shifts Scheffer et al. (2004) call for policies strengthening ecosystem resilience as events causing drastic regime shifts are difficult to predict and control. The stylized examples presented show allowing for drastic shifts causes higher threshold values. From this follows the benefits of preserving the current state do increase and hence supports the arguments for investing in ecosystem resilience.

The examples presented have been kept simple for clarity of exposition. A numerous number of models do exist modelling the same effects in continuous time continuous state frameworks including stochastic regime shifts as mentioned in the introduction. The size of the irreversibility effect as a measure of the economic costs of the ecosystem regime shifts does depend on the direct irreversible costs but also to what extend they can be reversed. The case of pest resistance illustrate that even if an ecosystem regime shift could be reversed having a regime shift might not be desirable from an economic point of view.

The results of the case study on ht-sugar beets illustrates an application of the irreversibility effect for decision making.

5 Conclusion

In this paper we have shown the multi-dimensional features of the irreversibility effect for the ex-ante assessment of social benefits and costs of a project. We have demonstrated the irreversibility effect and its effect on threshold levels by using very simple examples. They illustrate the differences between irreversible benefits and irreversible costs. In addition, the example of pest resistance shows the difference between irreversibility at the biological and economic level. While pest resistance can be considered reversible from a biological point of view, it may nevertheless result in irreversible costs. The different types of irreversibilities are summarised in a two dimensional matrix that we propose as a guideline for a complete ex-ante social benefit-cost-analysis of transgenic crops. An application for the decision to release herbicide tolerant sugar beets in the EU illustrates the use of the matrix.

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Annex I: Contributors to the report

This report is the result of discussions between all partners in the EXIOPOL consortium. It has been edited by Justus Wesseler. The different chapters were written by the following persons:

Chapter 1: *Justus Wesseler, Wageningen University*