ICAR

INSTITUTIONAL
CHANGE
IN AGRICULTURE AND
NATURAL RESOURCES

GOVERNING THE CO-EXISTENCE OF GM CROPS

Ex-Ante Regulation and Ex-Post Liability under Uncertainty and Irreversibility

VOLKER BECKMANN, CLAUDIO SOREGAROLI, JUSTUS WESSELER

ICAR Discussion Paper 12/2006

Discussion Paper

Institutional Change in Agriculture and Natural Resources (ICAR) Discussion Papers

Edited by Volker Beckmann and Konrad Hagedorn

Humboldt-Universität zu Berlin
Institut für Wirtschafts- und Sozialwissenschaften des Landbaus
Fachgebiet Ressourcenökonomie

Humboldt University Berlin
Department of Agricultural Economics and Social Sciences
Division of Resource Economics

Luisenstr. 56, D-10099 Berlin
Germany

Phone: ++49 30 20936305
Fax: ++ 49 30 20936497

Email: k.hagedorn@agrar.hu-berlin.de
v.beckmann@agrar.hu-berlin.de
http://www.agrar.hu-berlin.de/wisola/fg/ress/

ICAR Discussion Papers are reports prepared by members of the Division of Resource Economics, Humboldt University Berlin or external authors working on topics of institutions and institutional change in agriculture and natural resource management. The papers have received limited reviews. Views and opinions expressed do not necessarily represent those of the Division of Resource Economics. Comments are highly welcome and should be sent directly to the authors.

ISSN 1613-3455 (Printausgabe)
ISSN 1613-4862 (Internetausgabe)

Governing the Co-Existence of GM Crops

Ex-Ante Regulation and Ex-Post Liability under Uncertainty and Irreversibility

Volker Beckmann[1], *Claudio Soregaroli*[2], *Justus Wesseler*[3]

1) Department of Agricultural Economics and Social Sciences,
Humboldt University of Berlin, Germany
2) Università Cattolica del Sacro Cuore, Piacenza, Italy
3) Environmental Economics and Natural Resources Group,
Wageningen University
6700 EW Wageningen, The Netherlands
Phone: +31 317 482300, Fax: + 31 317 484933
e-mail: justus.wesseler@wur.nl

IACR Discussion Paper 12/2006

March 2006

Abstract
The future institutional environment for the co-existence of genetically modified (GM) crops, conventional crops and organic crops in Europe combines measures of ex-ante regulation and ex-post liability rules. Against this background we ask the following two questions: How does ex-ante regulation and ex-post liability under irreversibility and uncertainty affect the adoption of GM crops? What are the implications for regional agglomeration of GM and non-GM crops? Ex-ante regulations and ex-post liabilities for using GM crops will induce additional costs. These costs are modelled in a classical way. The model is advanced by including irreversibility and uncertainty and taking into account transaction costs of negotiating possible solutions with neighbouring farmers which are assumed to be partially irreversible. The results show that the design of ex-ante regulation and ex-post liability increases the value of waiting and results in less immediate adoption of the GM technology. Additionally, the rules and regulations in the EU do provide incentives for the regional agglomeration of GM and non-GM crops that are mainly driven by the irreversibility effect of the ex-ante regulatory and ex-post liability costs.

Keywords: Co-existence, GM crops, liability law, public regulation, technology adoption
JEL Codes: K13, O33, Q18

Acknowledgements
The third author acknowledges financial support from the EU under the ECOGEN project (Contract NO. QLK5-CT-2002-01666). The authors thank Catherine Murray and Christian Schleyer for helpful comments. Any remaining errors and omissions are the sole responsibility of the authors.

1 Introduction

The institutional environment for the co-existence of genetically modified (GM) crops, conventional crops and organic crops in Europe combines measures of ex-ante regulation and ex-post liability rules. Recognising Europe's heterogeneity in farm structures, crop patterns and legal environments, the European Commission decided to follow the principle of subsidiarity and states that "measures for coexistence should be developed and implemented by the Member States." (Commission of the European Communities 2003). It can be expected that the Member States will develop a variety of different measures that will have a profound impact on the adoption rate of GM crops. The discussion on co-existence and private liability for GM-technology, however, is not limited to Europe. There is an ongoing debate in the United States, Canada, New Zealand and other countries (see e.g. Smyth, Khachatourians and Phillips 2002; Kershen 2002; Conner 2003).

Against this background we ask the following two questions: How does ex-ante regulation and ex-post liability under irreversibility and uncertainty affect the adoption of GM crops? What are the implications for regional agglomeration of GM and non-GM crops?

Ex-ante regulations and ex-post liabilities governing the planting of GM crops will add additional costs for adopters in comparison to a situation where GM crops are treated the same as non-GM crops. These costs are modelled in a classical way starting with the approach by Kolstad, Ulen, and Johnson (1990) which is advanced by including irreversibility and uncertainty as in Soregaroli and Wesseler (2005). In this paper we introduce a different cost function that takes into account transaction costs of negotiating possible solutions with neighbouring farmers as suggested by Beckmann (2005). This new model is our main contribution. We also show how the rules and regulations affect the comparative advantage of different farm types and how they set incentives for regional agglomeration of farm types (GM or non-GM farms).

2 Assessing the Problem of Co-Existence

The problem of co-existence is a classical "problem of social costs". Farmers who plant GM crops may cause negative (or positive) external effects to non-GM or organic farmers by cross pollination through pollen drift or other forms of admixture.

The pollination, in principle, can be two sided. GM crops may affect non-GM crops but non-GM crops may also affect GM crops. It is important to note here that the same physical

effect, i.e. pollen flow, can have different economic impacts, depending on the institutional setting.

The institutional and regulatory setting defines the rules of what is or is not to be called GM. In this case, this largely depends on threshold levels and it is not surprising that the definition of the threshold is subject to a strong political debate. In the EU the current food-labelling threshold is 0.9% for GM food (Commission of the European Communities 2005)[1].

These specificities, the impact of the institutional setting and the threshold level for defining GM food, will be considered for developing a model for co-existence.

2.1 A Simple Model Defining Co-Existence

We start with a simple model for co-existence by following Beckmann and Wesseler (2005). Think about a region that consists of a number of farms *i= 1,…,k,* with risk-neutral farmers which show similar cropping patterns and share several borderlines and initially grow only one type of crops. Further, assume initially only non-GM crops are grown. The regional value of non-GM production, V_N, is then given by

$$V_N = P_N Y_N - C_N \tag{1a}$$

$$V_N = \sum_{i=1}^{k} v_{N_i} = \sum_{i=1}^{k} \left(p_{N_i} y_{N_i} - c_{Ni} \right) \tag{1b}$$

where P_N, Y_N, and C_N are the respective price, quantity and cost vectors for non-GM products at the regional level. Further, v_{N_i} indicates the farm level value of non-GM production and $p_{N_i}, y_{N_i}, c_{N_i}$ are the respective farm level price, quantity and cost vectors.

If all farmers in the region were to shift to the GM crop variety, e.g. from corn to Bt-corn[2], regulations to ensure non-GM farming are not necessary and the regional value of GM crop production, V_G, is given by:

$$V_G = P_G Y_G - C_G \tag{2a}$$

---

[1] It should be noted here that for organic farming no threshold has been decided yet. The European Commission proposes a 0.9% threshold level as well, which is heavily debated.

[2] Bt corn has been genetically engineered to contain *Bacillus thuringiensis* (Bt), a species of soil-borne bacteria. When a susceptible insect tries to feed on a GM crop expressing the Bt protein, it stops feeding and will die as a result of the binding of the Bt toxin to its gut wall.

$$V_G = \sum_{i=1}^{k} v_{G_i} = \sum_{i=1}^{k} p_{Gi} y_{Gi} - c_{Gi} \quad (2b)$$

with P_G, Y_G, and C_G as the respective price, quantity and cost vectors of GM crops at the regional level. Again v_{G_i} represents the farm level value of GM production and p_{G_i}, y_{G_i}, c_{G_i} are the respective price, quantity and cost vectors for GM crops at the individual farm level.[3]

Since it is expected that consumers are willing to pay a price premium for GM-free food, we assume further that the farm gate price of non-GM crops is universally higher than for GM crops[4]. This assumption is represented by the equation (3):

$$p_{N_i} > p_{G_i}, \forall i = 1,...,k \quad (3)$$

If the farm gate prices of GM crops are assumed to be lower than for non-GM crops, GM crops must allow for sufficient cost reductions or yield increases in order to be attractive to be grown. At least for one farmer the value of GM crop production must exceed the value of non-GM crops, $v_{G_i} > v_{N_i}$, otherwise GM crops will not be grown and *vice versa*.

Assume now, that the whole group of k farmers could be divided into two different subgroups. The first group, $i = 1,\ldots,h$, say group *A*, has a comparative advantage in non-GM crop production, $v_{Ni} \geq v_{Gi}$; the second group $i = k-h,\ldots,k$, say group *B*, has a comparative advantage in GM crop production, $v_{G_i} > v_{N_i}$. For notational clarity, we indicate farms belonging to group *A* with $i = 1,\ldots,h$ with the small letter *a* and farms belonging to group *B* with $i = k-h,\ldots,k$ with the small letter *b*. Different regions may show a different population structure with regard to the type of farms. One region may be populated mostly with type *A* farmers, another region mostly with type *B* farmers, and a third region may be equally populated by type *A* and *B* farmers. If the latter is the case, then the co-existence of both farm types, if it can be established cost free, will be socially preferable compared to the status quo and to the unified adoption of GM crops, since the value of co-existence in the region, *VC*, will exceed the value of uniform adoption as represented by equation (4):

$$VC = \sum_{a=1}^{h} v_{N_a} + \sum_{b=k-h}^{k} v_{G_b} > V_G, V_N \quad (4)$$

---

[3] Please note, refuge areas to control for pest resistance are implicitly considered in this model as part of the costs of planting the GM crops.

[4] However, there is no reason to believe that this should always be the case. It is also possible that the price of GM-food exceeds the price for non-GM products. In the following, however, we will not consider this case.

2.2 Co-Existence, Economic Damage and Technical Measures

Equation (4) assumes that there is no co-existence problem. However, if accidental pollen transfer from GM crops to non-GM crops occurs, the non-GM farmer may face the risk that his non-GM crops will be contaminated with pollen from GM crops. If, as a consequence, he cannot sell his product at a price premium, he will face an economic loss or damage, d_a. The occurrence and magnitude of the economic damages is influenced by a number of factors represented in equation (5a).

$$d_a = \begin{cases} 0 & \text{if } \dfrac{\psi_{N_a} Y_G}{y_{N_a}} < T \\ (p_{N_a} - p_{G_a}) y_{N_a} & \text{if } \dfrac{\psi_{N_a} Y_G}{y_{N_a}} \geq T \end{cases} \tag{5a}$$

$$D = \sum_{a=1}^{h} d_a \tag{5b}$$

The occurrence of the damage at the individual non-GM farm, d_a, is determined by (1) the quantity of GM crops grown in the region Y_G which is an expression for the current rate of adoption, (2) the diffusion coefficient ψ_{N_a} that indicates the farm and crop specific impact of pollen drifts from GM crops to non-GM crops and (3) the threshold, *T,* for the good being defined as GM or non-GM. As it was already argued, the threshold *T* is an important factor for the occurrence of economic damage. Economic damage occurs only if the fraction of GM crops in non-GM crops exceeds the threshold level. The magnitude of the damage is influenced by (1) the price difference, $p_{N_a} - p_{G_a}$ and the (2) quantity y_{N_a} of non-GM products affected. The damage, of course, is zero if the quantity of GM crops or non-GM crops is zero, if the price difference is zero or if the contamination is always below the threshold level. The total damage in the region, *D*, is the sum of the farm level damages, d_a.

The diffusion coefficient is of specific importance here. This coefficient can be influenced by different technical measures and management practices, i.e. by isolation distances between fields, buffer zones, pollen barriers, crop rotation systems or by genetic use restricted technologies (GURT) (e.g. van de Wiel, Groot, and den Nijs 2005). These management practices are either related to border management or to the spatial and temporal co-ordination of agricultural activities and can be subsumed as fencing activities. However, changing the diffusion coefficient requires the introduction of management practices resulting in additional

costs. If we denote m_i as the farm-level management practices and f_i as the farm-level fencing costs of these practices, the following relationships are assumed:

$$\psi_i = \psi_i(m_i, m_{k,i\notin k}) \tag{6a}$$

$$f_i = f_i\left(m_i\left(y_{N_i}, y_{G_i}, Y_N, Y_G\right)\right) \tag{6b}$$

$$F = \sum_{i=1}^{k} f_i = \sum_{a=1}^{h} f_a + \sum_{b=1}^{k-h} f_b \tag{6c}$$

The diffusion coefficient at the farm level, ψ_i, is influenced by the farm management practices m_i but also by the management practices of all other farms. Let's take the example of the buffer zone as one management system and two neighbouring farms. The diffusion coefficient can be reduced if the buffer zone is implemented by a farm that grows non-GM crops and it will be reduced even more if the GM farm establishes a buffer zone as well. However, equation (6a) indicates that because of the interdependencies in management there is a coordination problem between the management practices adopted by different farms. The costs of establishing the management and fencing systems as in equation (6b) are not only dependent on the management practices of the farmer, m_i, but also indirectly on the quantity of non-GM (or GM) crops grown on the farm and the quantity of non-GM crops and GM crops grown in the region. Just to give an example, it makes a difference if a non-GM farm is surrounded by one GM farmer and four non-GM farmers or by five GM farmers. Finally, the management and fencing costs in the region are the sum of the individual management and fencing costs as indicated by equation (6c). Through coordinated action farmers may reduce damage and/or fencing costs. They can agree on voluntary solutions such as different rotation practices, planting times or buffer zones. These co-ordination activities are not cost free because of transaction costs. For the simplification of the exposition we assume transaction costs to be considered under fencing and damage costs.

Considering the additional costs discussed above equation (4) has to be rewritten:

$$VC = \sum_{i=1}^{h} v_{G_i} + \sum_{i=k-h}^{k} v_{N_i} - \sum_{i=1}^{k} d_i - \sum_{i=1}^{k} f_i > V_G, V_N; \quad \sum_{i=1}^{k} d_i, \sum_{i=1}^{k} f_i \geq 0 \tag{7}$$

Now, the regional value of co-existence is the sum of the values of GM and non-GM crops at the farm level minus the sum of damage and/or fencing costs and equation (7) reflects the sum of the individual decisions.

2.3 Liability Rights and Distribution of Costs and Benefits

To incorporate different distributions of property rights in the form of liability rights in the analysis, let us denote vc_{N_i} as the farm level co-existence value of non-GM crops and vc_{G_i} as the farm level co-existence value of GM crops. We introduce a superscript ℓ that indicates if the GM farmer is liable for the damages he causes and *n* if he is not. We assume further that there are no additional costs except for the damage costs of holding the GM farmer liable for cross pollination and hence there is no uncertainty involved in proving admixture. Under this setting two different liability systems are discussed.

2.3.1 GM farmer not liable

If farmers have the unrestricted right to grow GM crops and are not liable, every farmer switching to GM technology will reduce the value of non-GM crops on fields in the neighbourhood due to possible economic damages from the GM field. The co-existence value of non-GM farming of farm *i*, $vc^n_{N_i}$, will be reduced if neighbouring farms plant GM crops by the expected damage d_i and/or by the costs f_i of the management and fencing practices that prevent potential damages. The co-existence value of GM farming, however, does not change for farmer *i*:

$$vc^n_{N_i} = v_{N_i} - d_i - f_i \tag{8a}$$

$$vc^n_{G_i} = v_{G_i} \tag{8b}$$

Farmer *i* will now choose to plant GM crops, if $vc^n_{G_i} > vc^n_{N_i}$. The distribution of rights and therefore costs and benefits as indicated by equation (8a) and (8b) can be assumed not only to influence distribution of economic benefits but also technology adaptation and investments in the management and fencing system. Under the circumstances described, a GM farmer has no incentive to invest in management and fencing practices that prevent damages. The non-GM farmer, however, has an incentive to invest in management systems that prevent damages. Cost minimizing behaviour requires that the non-GM farmer introduces management technologies up to the level where the marginal costs of these technologies are equal to the avoided marginal damages. If the damage and/or the management and fencing costs exceed the incremental value of non-GM crops, $d_i + f_i > v_{N_i} - v_{G_i}$, the farmer will stop non-GM production. Thus, this type of liability rights increases the adoption rate of GM technology.

However, as long as the equation does not hold for all farmers in group A, non-GM crop farming will not disappear.

2.3.2 GM farmer liable

The costs are distributed in a different way if the potential GM farmer is liable. If the GM farmer causes damages to the non-GM farmer, he has to pay compensation payments cp_{G_i} at the rate of the damage. The damage could be caused on more than one farm.[5] The compensation payment sets incentives for the GM farmer to undertake managing and fencing practices that reduce the damages. The value of GM farming therefore will be reduced by the compensation payments and the fencing costs. The value of non-GM farming will remain the same since possible economic losses are fully compensated for by the GM farmer.

$$vc_{N_i}^{\ell} = v_{N_i} \tag{9a}$$

$$vc_{G_i}^{\ell} = v_{G_i} - cp_{G_i} - f_i \tag{9b}$$

If the expected compensation payments for economic damages and/or the fencing costs exceed the value of GM production, $cp_{Gi} + f_i > v_{Gi} - v_{Ni}$ or $\Delta vc_{G_i}^{\ell} \equiv vc_{G_i}^{\ell} - v_{N_i} < 0$, GM crops will be prevented from being grown.

2.4 A Definition of Co-Existence

The previous discussion about co-existence now allows us to define the term co-existence:

> *"A state described by a set of policies exogenous to the farmers that results in the planting of 'organic and/or non-organic-non-GM' and 'GM crops' at the same point in time in a pre-defined region with at least one farm where* $vc_{G_i}^{n} > vc_{N_i}^{n}$ *and one where* $vc_{G_i}^{n} < vc_{N_i}^{n}$ *under a GM farmer property right system and at least one farm where* $vc_{G_i}^{\ell} > vc_{N_i}^{\ell}$ *and one where* $vc_{G_i}^{\ell} < vc_{N_i}^{\ell}$ *under a non-GM farmer property right system."*

The definition of co-existence includes exogenous policies such as ex-ante regulations and ex-post liability rules. So far, we have not discussed how those policies do affect the value of co-

[5] For simplicity we assume that the source of GM-pollen can be clearly identified, a system similar to the German one with total liable adhesion. The quality of our results does not change, if we assume that a group of farmers will be held liable, such as under the Danish system, only the compensation payment per GM farmer will be reduced.

existence. For the analysis we will assume that the property right is with the non-GM farmer, meaning to say he has the right to plant non-GM crops and farmers planting GM crops have to compensate and/or prevent damages to non-GM farmers. This system reflects the current situation in the EU.

3 Ex-Ante Regulation and Ex-Post Liability

3.1 Co-Existence Value under Ex-Ante Regulation and Ex-Post Liability Rules

The starting point is the definition of the GM farmer's value function under ex-ante regulation and ex-post liability rules. The value function of the GM farmer will be affected as complying with regulations and the possibility of facing ex-post liability for damages from cross pollination adds additional costs to those farmers that plant GM crops. The value of planting GM crops at farm *i* can now be defined as the value from GM cultivation, $p_{Gi}y_{Gi} - c_{Gi}$, minus the costs related to liability and its control, λ_i. The co-existence value of GM farming under ex-ante regulation and ex-post liability:

$$\widehat{vc_{G_i}^{\ell}} = p_{Gi}y_{Gi} - c_{Gi} - \lambda_i \qquad (10)$$

The expected costs related to liability are the sum of the costs of respecting ex-ante regulations, r_i, and the value of ex-post tort liability tl_i:

$$\lambda_i = E(r_i + tl_i)\,. \qquad (11)$$

The regulatory costs introduced in equation (11), r_i, are the sum of the fencing and compensation costs in equation (9b) under certainty and λ_i the sum including legal uncertainty. Following Kolstad, Ulen, and Johnson (1990) equation (11) can be written as

$$tl_i = \mu_i \cdot d_i \cdot j_i \qquad (12)$$

where, μ_i is the probability of causing an accident, in this case contamination of the neighbouring non-GM fields, d_i is the monetary value of the damage, and j_i is the probability that the injurer will pay the damages. In our case, j_i, can be interpreted as a function of the court's view and the probability of being sued by the neighbour who has suffered damage. From the previous equations the co-existence value function for the GM farmer can be formulated as follows:

$$\widehat{vc_{G_i}^{\ell}} = v_{G_i} - r_i\left(s, reg\right) - \mu_i(s, reg)d_i\left(s, reg\right)j_i(law) \qquad (13)$$

where *s* is the size of GM crops planted, *reg* is the enforced GM legal standard for the region (e.g. country or federal state) and *law* is the tort liability system of the region.

Interpreting the variable *reg* as the minimum distance, *z*, one of the most common forms of ex-ante regulation, between the GM crop and the neighbouring non-GM crop we can write equation (11) as:

$$\widehat{vc_{G_i}^{\ell}} = v_{G_i} - r_i(s,z) - \mu_i(s,z) d_i(s,z)\, j_i(law) \tag{14}$$

A profit maximizing farmer *i* would adopt GM crops if $\Delta\widehat{vc_{G_i}^{\ell}} \equiv \widehat{vc_{G_i}^{\ell}} - v_{N_i} > 0$.

3.2 Introducing Irreversibility and Uncertainty

In the previous discussion it was assumed that incremental benefits are certain and the farmer did not face reduced costs while deciding to adopt the GM technology. However, it could be the case that some of the costs are irreversible: for example, the GM crop requires specific machinery or the GM cultivation could make it difficult for the farmer to switch back to the non-GM status. These difficulties could include additional practices for the control of volunteers or a required minimum number of years of non-GM cultivation for a field to be considered for producing non-GM products. The multi-period time frame also adds uncertainty to the farmers' adoption decision as future yields, prices and costs are not generally known with certainty as well as flexibility regarding adoption timing of GM crops.

In the presence of net-irreversible costs, uncertainty and flexibility, the value of a GM crop is not simply the difference between the present value of future benefits and costs but the sum of this difference plus the value of the option to plant GM crops (Wesseler 2003). More formally, when some costs are irreversible, costs and benefits are uncertain and the decision to adopt can be postponed, a profit maximizing farmer maximizes the option value of the adoption possibility. Hence, we can write for the adoption decision under irreversibility, temporal uncertainty and flexibility excluding ex-ante regulation and ex-post liability rules, with ~ indicating the value of co-existence under irreversibility, temporal uncertainty, and flexibility:

$$F\left(\Delta\widetilde{vc_{G_i}}\right) = \max E\left[\left(\int_T^{\infty} \Delta\widetilde{vc_{G_i}}(v_{G_i}, v_{N_i}) e^{-\rho(t-T)} dt - IR_i\right) e^{-\rho T}\right] \tag{15}$$

or including ex-ante regulation and ex-post liability rules:

$$F\left(\Delta\widetilde{vc}_{G_i}^{\ell}\right)=\max E\left[\left(\int_{T}^{\infty}\Delta\widetilde{vc}_{G_i}^{\ell}\left(v_{G_i},v_{N_i},r_i,tl_i\right)e^{-\rho(t-T)}-IR_i^{\ell}\right)e^{-\rho T}\right] \tag{16}$$

where IR_i and IR_i^{ℓ} are the net-irreversible costs respectively and ρ the discount rate.

There is some potential controversy about what we mean by net-irreversible costs. IR_i indicate the net-irreversible costs, the difference between irreversible costs I_i and irreversible benefits R_i, of farmers who adopt GM crops. Both, I_i and R_i, are those at the private level and include sunk costs such as new machinery for higher density planting of herbicide tolerant soy beans or positive health benefits due to a change in pesticide use (Weaver and Wesseler 2004). IR_i^{ℓ} indicates the net-irreversible costs under regulation and liability rules. IR_i^{ℓ} includes in addition to IR_i irreversible transaction costs, IR_i^{tc}, that may arise due to negotiations with neighbouring farmers.[6]

$$IR_i^{\ell}=IR_i+IR_i^{tc} \tag{17}$$

with

$$IR_i=I_i-R_i>0,\forall i=1,...,k \tag{17a}$$

$$IR_i^{tc}=I_i^{tc}-R_i^{tc}>0,\forall i=1,...,k \tag{17b}$$

The uncertainty that in combination with the net-irreversible costs creates the option value for adopting GM crops is represented by the following stochastic process:

$$d\left(\Delta vc_{G_i}^{\ell}-r_i\right)=\alpha\left(\Delta vc_{G_i}^{\ell}-r_i\right)dt+\sigma\left(\Delta vc_{G_i}^{\ell}-r_i\right)dz+\left(\Delta vc_{G_i}^{\ell}-r_i\right)dq_i \tag{18}$$

where $\left(\Delta vc_{G_i}^{\ell}-r_i\right)$ evolves under a combined geometric Brownian motion and Poisson process. α is the drift of the Brownian motion, dz is the increment of a Wiener process, dt is the marginal increment in time and dq_i is the increment of a Poisson process. The first two terms on the right-hand-side of equation (18) are common for modelling incremental benefits of GM crops under irreversibility and uncertainty (e.g. Demont, Wesseler, and Tollens 2004; Morel et al. 2003; Wesseler 2003). The third term represents tort liability modelled as the risk of a jump in the profit when the farmer is held liable. More precisely,

[6] Some of the transaction costs are assumed to be irreversible. If farmers move out of planting GM crops e.g, time and money spent on arrangements with neighbours to comply with and reduce regulatory and liability costs are worthless.

$dz = \varepsilon_t \sqrt{dt}$, and

$$dq_i = \begin{cases} 0 & \text{with probability 1-}\gamma_i\text{dt} \\ -\phi_i & \text{with probability } \gamma_i\text{dt} \end{cases} \tag{19}$$

where ε_t is normally distributed with zero mean and unit standard deviation, γ_i is the mean arrival rate of a Poisson process, and ϕ_i the percentage of the ex-post liability costs of $\left(\Delta vc_{G_i}^{\ell} - r_i\right)$.

From the above equation and the opportune boundary conditions the standard rule for the adoption decision under irreversibility and uncertainty, assuming $\phi = 1$, can be derived (Dixit and Pindyck 1994):[7]

$$\left(\Delta vc_{G_i}^{\ell} - r_i\right) > \left(\left[\Delta vc_{G_i}^{\ell} - r_i\right]^*\right) = \left(\frac{\beta_{1_i}}{\beta_{1_i} - 1}\right)(\rho - \alpha_i + \gamma_i) IR_i^{\ell} \tag{20}$$

Equation (20) says adopt GM crops if the current incremental co-existence value of GM farming, $\Delta vc_{G_i}^{\ell}$ minus the regulatory costs r_i are greater than the hurdle value $\left[\Delta vc_{G_i}^{\ell} - r_i\right]^*$. This hurdle value depends among others on the regulatory and liability costs as they have an impact on the irreversible transaction costs and due to tort liability an impact on γ_i.

Please note, we get a farm specific hurdle rate, even if the drift and variance rate of the geometric Brownian motion are homogenous over all farms as the mean arrival rate of the Poisson process is farm specific and depends on the landscape and number and distance of non-GM farms in the neighbourhood.

With the now specified decision rule of adopting GM crops considering ex-ante regulatory and ex-post liability costs under irreversibility and uncertainty, we can have a closer look at the co-existence issue and regional agglomeration.

---

[7] ϕ_i is assumed to be 1 to derive an analytical solution. Using a different value for ϕ_i requires finding a solution numerically.

4 Adoption and Spatial Agglomeration Effects under Irreversibility and Uncertainty

4.1 Adoption Effects

To see the effects of ex-ante regulation and ex-post liability rules on adoption and regional agglomeration we start by looking at the initial situation without any irreversibility and uncertainty. This situation is depicted in Figure 1. The horizontal axis illustrates the benefits for farmers staying non-GM and the vertical axis the benefits for becoming a GM farmer. Point A^1 indicates a situation where the incremental benefits from planting non-GM crops for farmer *a* are positive $\left(v_{N_a} > v_{G_a}\right)$, whereas at point B^1 the incremental benefits from GM crops for farmer *b* are positive $\left(v_{G_b} > v_{N_b}\right)$. Point C^1 indicates the comparative advantage of those two farms under coexistence. As the incremental benefits of farmer *b* are larger than the incremental benefits of farmer *a* point C^1 is above the 45°-degree line indicating a comparative advantage for farmer *b*.

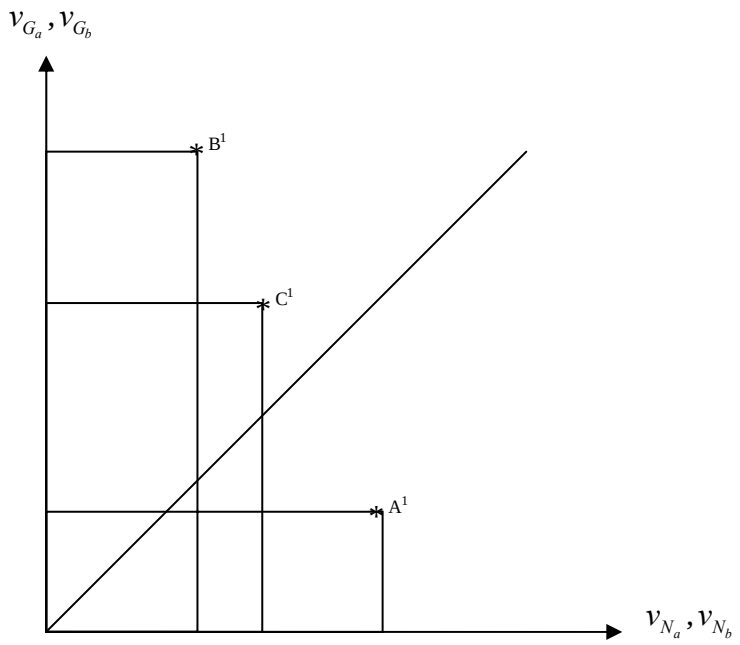

Figure 1: Distribution of adopter and non-adopters without net-irreversible costs and ex-ante regulation and ex-post liability

The situation changes with the introduction of irreversibility and uncertainty as depicted in Figure 2. Irreversibility and uncertainty at the production level have the following implications. Incremental benefits from GM crops are reduced due to the irreversibility and uncertainty effect (the value of waiting). This is illustrated by a vertical downward movement of farmer *b* from point B^1 to point B^2. If farmer *a* is not affected the new comparative advantage is at point $C^2_{w/o}$ which is still above the 45°-degree line. But it is also reasonable to assume that farmer *a* would face irreversibility and uncertainty as well if s/he would consider adopting GM crops. Hence, under irreversibility and uncertainty the benefits of farmer *a* for staying non-GM do increase. This is indicated by a horizontal move from point A^1 to point A^2. The new comparative advantage is indicated by point C^2_w. This point is located below the 45°-degree line. Now, the comparative advantage has moved from GM farmer *b* to the non-GM farmer *a*. This effect is independent of ex-ante regulatory and ex-post liability costs and has already been studied for the adoption of GM crops (e.g. Demont, Wesseler, and Tollens 2004; Morrel et al., 2003; Scatasta, Wesseler, and Demont 2006).

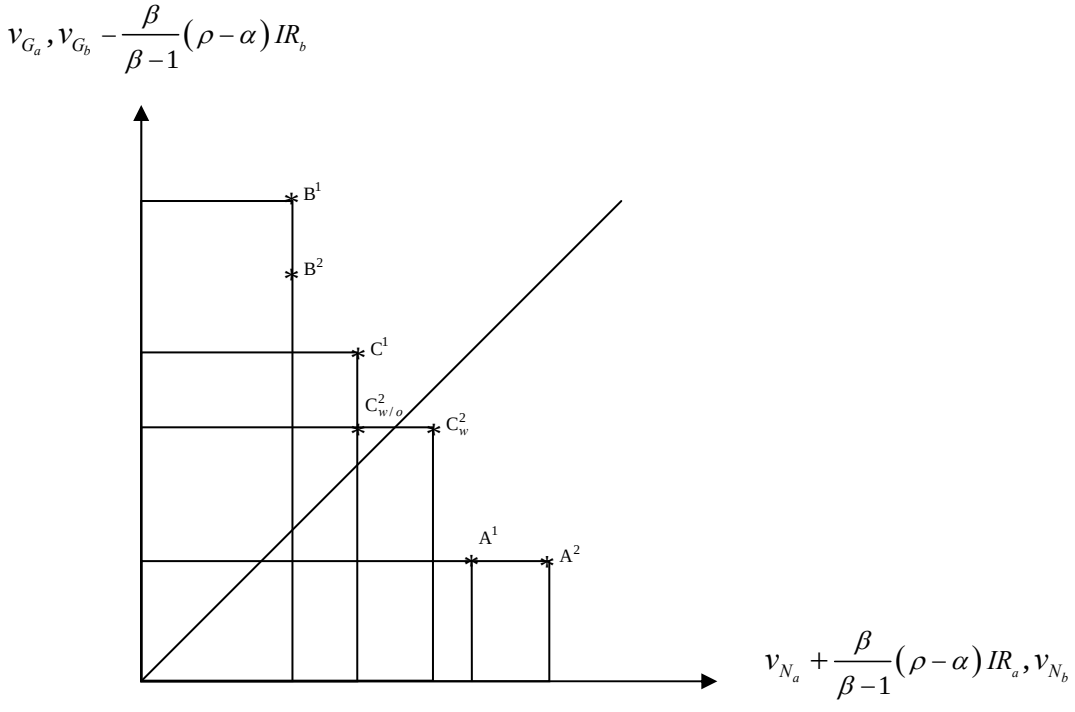

Figure 2: Distribution of adopter and non-adopters with net-irreversible production costs and without ex-ante regulation and ex-post liability

Now, if the GM farmer is liable for possible damages, s/he will only be willing to plant GM crops as long as the costs for complying with the regulations does not exceed the incremental value of GM production. The new situation is depicted in Figure 3. Again, we can observe two main effects. First, ex-ante regulatory and ex-post liability costs increase the hurdle value of adoption. This is indicated by a downward vertical move from point B^2 to point B^3. Please note, planting GM crops is still profitable for farmer *b*. Second, the value of staying non-GM either remains the same or further increases.

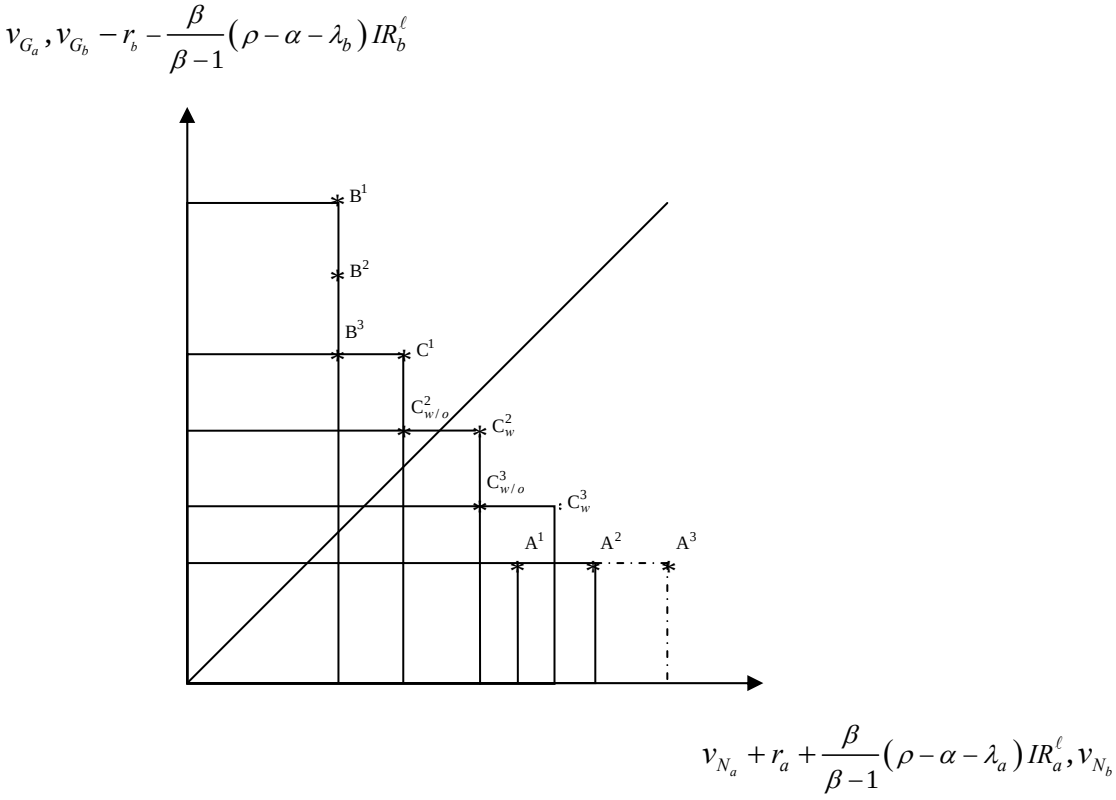

Figure 3: Distribution of adopter and non-adopters with net-irreversible production costs under ex-ante regulation and ex-post liability

If the non-GM farmer is surrounded by GM farms only, the farmer does not have to bear ex-ante regulatory and/or ex-post liability costs if s/he becomes a GM farmer. There is no non-GM farmer left who could claim the right for producing non-GM crops. In this case farmer *a* remains at point A^2 and the comparative advantage for staying non-GM is indicated by point $C^3_{w/o}$. In case there are other non-GM farmers in the neighbourhood switching to GM crops

adds additional compliance costs for farmer *a*. Hence, the benefits of staying non-GM further increase as indicated by point A^3. The comparative advantage for the non-GM farmer further increases as indicated by the move to the right from point $C^3_{w/o}$ to point C^3_w.

It is important to recognize, that liability increases the irreversible costs due to additional negotiation costs. Every unit of irreversible costs demands more than one unit of incremental benefits. Regulation and liability rules have two effects on potential adopters. First, regulations directly decrease the incremental benefits (see equation (16)). The adoption rate would decrease even without ex-post liability. Second, ex-post liability increases the hurdle rate as $\partial\left(\frac{\beta}{\beta-1}\right)\Big/\partial\gamma > 0$ and this further increases the required incremental benefits for adoption.

Figure 3 clearly shows that ex-ante regulatory and ex-post liability costs for GM farmers reduce the adoption of the technology and favours non-GM farming. The opposite can be shown to hold for providing the GM farmer with the property right of planting GM crops. The effect can be explained by using Figure 2. If the fencing costs of the non-GM farmer are equivalent to the irreversibility effect at production level then farmer *a* would move back from point A^2 to point A^1. The comparative advantage in the case of the production right is with the GM farmer and the point illustrating the situation is point $C^2_{w/o}$.

4.2 Agglomeration Effects

The rules and regulations governing co-existence set incentives for the GM farmer to collaborate with neighbours to reduce ex-ante regulatory and ex-post liability costs. Consider Figure 4 which is a comparison between the benefits and costs before and after the introduction of regulation and liability.

The horizontal axis represents non-GM farms with $v_{N_a} - v_{G_a} > 0$ and the vertical axis GM farms with $v_{G_b} - v_{N_b} > 0$. Any point in the first quadrant indicates the situation between a non-GM and GM farm. All points above (below) the 45°-degree line indicate situations where the incremental benefits of the GM (non-GM) farmer are larger than the incremental benefits for the non-GM (GM) farmer.

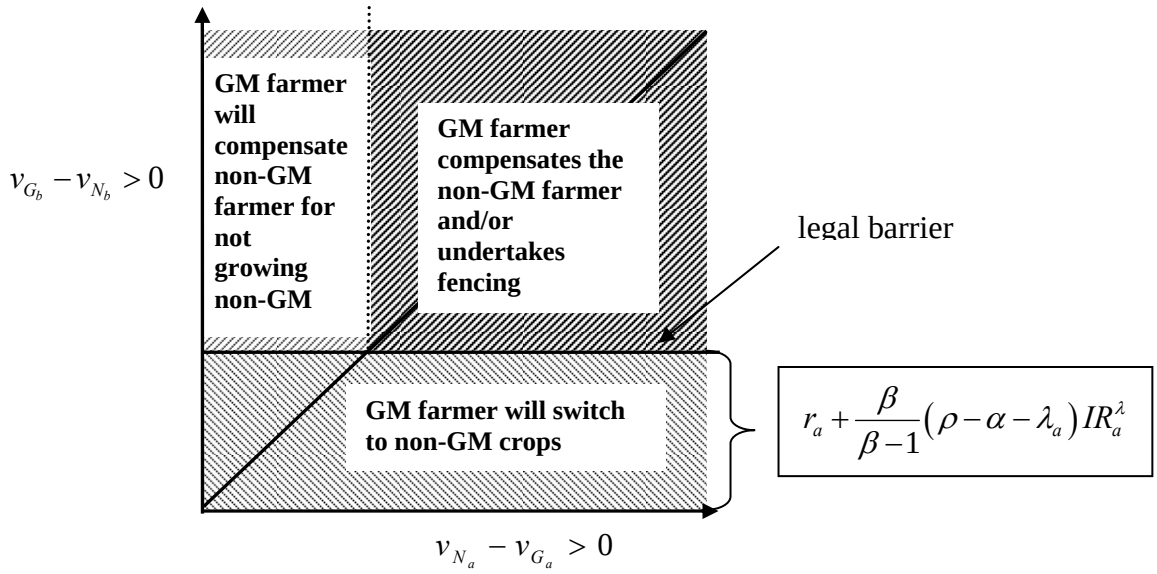

Figure 4: Agglomeration effects induced by ex-ante regulation and ex-post liability

Three situations to adapt to ex ante regulations and ex post liability rules do exist. If the incremental benefits $v_{G_b} - v_{N_b}$ for GM farmers are less than the costs to comply with the rules and regulation, they are below the legal barrier, they will not adopt the GM crop and become (or stay) non-GM farmers. This will be a likely situation for areas where the benefits from the technology are small and hence, potential adopters will stay non-GM. In those regions there will be no co-existence between GM and non-GM farmers. This is in Figure 4 the shaded area below the legal barrier.

In those areas where the incremental benefits for GM farmers are above the legal barrier and the incremental benefits for the farmer staying non-GM are smaller than the incremental benefits for the GM farmer, GM farmers can compensate the non-GM farmers and convince them to become GM farmers as well. This is the left shaded area above the legal barrier in Figure 4. In those regions an agglomeration of GM farmers will happen and again there will be no co-existence between GM and non-GM farmers.

The third situation resembles regions where GM as well as non-GM farmers show high incremental benefits. In those regions the incentives for the GM farmer is to grow the crops, comply with the regulations and, in case of liability, pay for the possible damage. The GM farmer has no economic incentive to compensate the neighbouring non-GM farmer to become a GM farmer. There is also no economic incentive in that situation to become a non-GM farmer. In this situation co-existence between GM and non-GM farmers will emerge.

5 Conclusions

The difference in the distribution of property rights can explain the different rates of adoption of GM crops. In the US where the property right of planting is with the GM farmer, a relatively high rate of adoption can be observed. In the EU the property right of planting is with the non-GM farmer. Several countries such as Denmark and Germany have adopted a policy combining ex-ante regulations and ex-post liability rules to govern the planting of GM crops. Our analysis shows how current regulations and liability rules increase the irreversible costs of adoption and hence decrease the potential adoption of the technology. This has important implications for countries that still consider whether or not they should introduce GM crops and how the planting of the crops should be governed.

The difference in incremental benefits and costs between GM and non-GM farmers provide incentives for regional agglomeration of either GM or non-GM farms. We show that the incremental benefits for becoming a GM farmer need to increase due to the irreversibility effect of the ex-ante regulations and ex-post liability rules compared to a situation without regulations and liability rules. Minimum distance requirements between non-GM and GM farms increases the minimum farm size necessary for adopting the technology and therefore has a farm size effect as already pointed out by Beckmann (2005). The irreversibility effect of ex-ante regulations and ex-post liability rules increase the costs of minimum distance policies and hence increase the minimum farm size for adoption.

The question to what extent ex-ante regulation and ex-post liability do prevent the adoption of GM crops in Europe is an empirical one. We have provided with our analysis a theoretical framework that can be used for such an empirical study.

References

Beckmann, V. (2005). Comment on Soregaroli and Wesseler: Minimum distance requirements and liability: implications for co-existence. In J. Wesseler (ed.): *Environmental Costs and Benefits of Transgenic Crops*. Dordrecht, NL: Springer, 183-184.

Beckmann, V. and J. Wesseler (2005). Spatial Dimension of Externalities and the Coase Theorem: Implications for Co-existence of Transgenic Crops. Working Paper Mansholt Graduate School MWP-20, Wageningen University.

Commission of the European Communities (2005). Questions and Answers on the Regulation of GMOs in the European Union. Available at http://europa.eu.int/comm/food/food/biotechnology/gmfood/qanda_en.htm. Update: 24-10-2005.

Commission of the European Communities (2003). Commission Recommendation of 23 July 2003 on guidelines for the development of national strategies and best practices to ensure the coexistence of genetically modified crops with conventional and organic farming. Official Journal of the European Communities L189/36-47, 29.7.2003.

Conner, D.S. (2003). Pesticides and Genetic Drift: Alternative Property Rights Scenarios. *Choices*, 5-7.

Demont, M., J. Wesseler and E. Tollens (2004). Biodiversity versus transgenic sugar beet: the one euro question. *European Review of Agricultural Economics* 31 (1), 1–18.

Dixit, A. and R.S. Pindyck (1994). Investment under Uncertainty. Princeton, NJ: Princeton University Press.

Kershen, D.L. (2002). Legal Liability Issues in Agricultural Biotechnology. National AgLaw Center Publications. Univerity of Arkansas, School of Law.

Kolstad, C.D., T.S. Ulen, and G.V. Johnson (1990). Ex Post Liability for Harm vs. Ex Ante Safty Regulation: Substitutes or Compliments. *American Economic Review* 80, 888-901.

Morel, B., Farrow, S., Wu, F. and Casman, E. (2003). Pesticide resistance, the precautionary principle, and the regulation of Bt Corn: real option and rational option approaches to decision-making. In: R. Laxminarayan (ed.) *Battling Resistance to Antibiotics and Pesticides*. Washington, D.C.: Resources for the Future, 184-213.

Scatasta, S., J. Wesseler, M. Demont. 2006. Irreversibility, Uncertainty, and the Adoption of Transgenic Crops: Experiences from Applications to HT sugar beet, HT corn, and Bt Corn. In: Julian Alston, Richard Just, and David Zilberman (eds.): *Economics of Regulation of Agricultural Biotechnology*, Chapter 1, 1-26. Berlin: Springer. In press.

Smyth, S., G.G. Khachatourians, and P.W.B. Phillips. 2002. Liabilities and Economics of Transgenetic Crops. *Nature Biotechnology* 20:537-541.

Soregaroli, C. and J. Wesseler (2005). Minimum distance requirements and liability: implications for co-existence. In J. Wesseler (ed.): *Environmental Costs and Benefits of Transgenic Crops*. Dordrecht, NL: Springer, 165-182.

van de Wiel, C., M. Groot and H. den Nijs (2005). Gene flow from crops to wild plants and its population ecological consequences in the context of GM-crop biosafety, including some recent experiences from lettuce. In J. Wesseler (ed.): *Environmental Costs and Benefits of Transgenic Crops*. Dordrecht, NL: Springer, 97-110.

Weaver, R.D. and J. Wesseler (2004): Monopolistic pricing power for transgenic crops when technology adopters face irreversible benefits and costs. *Applied Economics Letters* 15(15):969-973.

Wesseler, J. (2003). Resistance Economics of Transgenic Crops. A Real Option Approach. In: R. Laxminarayan (ed.), *Battling Resistance to Antibiotics. An Economic Approach*. Washington, DC: Resources for the Future, 214-237.

Institutional Change in Agriculture and Natural Resources (ICAR) Discussion Papers

Edited by Volker Beckmann and Konrad Hagedorn

12/2006 Volker Beckmann, Claudio Soregaroli, Justus Wesseler: Governing the Co-Existence of GM Crops: Ex-Ante Regulation and Ex-Post Liability under Uncertainty and Irreversibility, March 2006.

11/2005 Rauchenecker, Katharina und Volker Beckmann. Jagdgenossenschaften und Wildtiermanagement. Zur Rolle der Zwangsmitgliedschaft, November 2005. Erscheint in *Zeitschrift für Umweltpolitik und Umweltrecht*.

10/2005 Ayalneh Bogale and Benedikt Korf: To Share or Not To Share?(Non-)Violence, Scarcity and Resource Access in Somali Region, Ethiopia, July 2005. Forthcoming in *Journal of Development Studies.*

9/2005 Catherine Murray: Social Capital and Cooperation in Central and Eastern Europe. A Theoretical Perspective, June 2005.

8/2005 Stefan Geyler und Robert Holländer: Ein Vergleich von zentralen und dezentralen Lösungen zur Abwasserentsorgung im ländlichen Raum, April 2005.

7/2005 Timothy Moss: „Dissecting Institutions“: Bestandteile einer institutionellen Konfiguration am Beispiel der Wasserwirtschaft, April 2005.

6/2005 Jan Monsees: Operationalisierungsprobleme einer vergleichenden Institutionenanalyse zur Gewässerunterhaltung, April 2005.
Published as: Monsees, Jan (2005): Operationaliserungsprobleme einer vergleichenden Institutionenanalyse am Beispiel Gewässerunterhaltung. *List Forum für Wirtschafts- und Finanzpolitik* 31 (2): 139-161.

5/2005 Andréanne Léger: Intellectual Property Rights and their Impacts in Developing Countries. An Empirical Analysis of Maize Breeding in Mexico, January 2005.
Published as: Léger, Andréanne (2005). Intellectual property rights in Mexico: Do they play a role? *World Development* 33 (11), 1865-1879.

4/2004 Jörg Eggers, Lutz Laschewski and Christian Schleyer: Agri-Environmental Policy in Germany. Understanding the Role of Regional Administration, December 2004.

3/2004 Annette Hurrelmann: Analysing Agricultural Land Markets as Organisations. An Empirical Study in Poland, November 2004.

2/2004 Stefan Jungcurt: The Politics of Incoherence: A Framework for the Analysis of Functional Overlap in International Governance as Two-Level Game, August 2004.

1/2003 Benedikt Korf: Conflict - Threat or Opportunity? War, Livelihoods, and Vulnerability in Sri Lanka, Oktober 2003.
Published as: Korf, Benedikt (2004) "War, Livelihoods and Vulnerability in Sri Lanka", *Development and Change* 35(2), 275-295.

ISSN 1613-3455 (Printausgabe)
ISSN 1613-4862 (Internetausgabe)
http://www.agrar.hu-berlin.de/wisola/fg/ress/icar