High-Yielding Genetically Modified Wheat in Germany: Economic Impact Assessment of its Potential

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Abstract

A novel genetically modified (GM) wheat variety (HOSUT) shows yield increasing potential of ca. 28%. We apply the real options concept of Maximum Incremental Social Tolerable Irreversible Costs (MISTICs) to conduct an ex-ante assessment of the potential economic impact of HOSUT wheat for Germany. In different scenarios cost and benefits associated with the adoption of this yield-increasing innovation are analyzed. Our results indicate that not authorizing HOSUT wheat is correct if German society values the hazard of social irreversible costs from this GM technology to be between € 7.75 and € 12.78 per citizen or more, depending on the scenario.

Keywords: Real options, GM wheat, yield increase, uncertainty, irreversibility

1 Introduction

Transgenic or genetically modified (GM) crops offer various potential benefits (Carpenter and Gianessi, 1999, Qaim, 2009, Zilberman, et al., 2010) but also raises society's concerns about potential irreversible health and environmental hazards (Weale, 2010). The consideration of both is important for deregulation decisions by society's institutions (e.g. European Commission). The regulatory challenge of whether to deregulate or ban for GM high-yielding HOSUT wheat variety is the motivation of this research.

20% of the world's calorie and protein demand is met by wheat (Shiferaw, et al., 2013). By that wheat is one of the most important food for human nutrition and is crucial for food security. In 2012, the global wheat production was ca. 670 mil. tons. The world's biggest producers are China, India and the U.S.A.. With ca. 3% of the global production is Germany the worlds' 9th biggest wheat producer (FAO, 2015). A sustainable and at the same time increasing global wheat production is essential to cope with the challenges of food security for a growing human population (Reynolds, et al., 2009). Numerous innovations in agricultural production and breeding productivity guaranteed a stable yield increase in the past years. Breeding techniques have developed from weak forms of selection, to more precise selection in combination with mutation, inbred, hybrid and biotechnology or genetically modified organism (GMO). Only the latter technology raises broad concerns across societies, especially in the EU (Gaskell, et al., 2010).

Researchers at the publically funded IPK[1] in Gatersleben, Germany, used genetic modification (GM) technology to develop novel winter wheat lines (HOSUT) with high yield potential. The researchers were able to introduce the barley sucrose transporter HvSUT1, controlled by the barley Hordein B1 promoter, into the conventional winter wheat line; Certo. The results of the breeding experiment were different HOSUT wheat lines. Three of the HOSUT wheat lines were grown over three years in micro-plots under field-like conditions in semi-controlled glass houses. Grain yield per plot significantly increased by average 28%, together with higher total protein yield, but lower protein concentration, and higher iron and zinc concentration (both increased by ca. 30%) when compared to the non-transformed control line (Saalbach, et al., 2014).

Independent from the state of development of HOSUT wheat, the introduction of GM wheat lines into the European Union or German market seems to be very unlikely under the current social and political acceptance of GMOs. However, an economic impact assessment can help to structure the political decision about the support of research and development of the innovation. In this study we will do an ex-ante economic impact assessment for a 28% yield increasing wheat innovation for Germany. The focus on Germany stems from the fact that so far HOSUT wheat lines have only be tested under German climate conditions. We will analyse the potential economic impact potential of an intermediate release of HOSUT wheat considering private and social reversible and irreversible costs and benefits and determine Maximum Incremental Social Tolerable Irreversible Costs (MISTICs). The theoretical concept of MISTICs is based real options (RO) theory. RO theory, as developed by McDonald and Siegel (1986), Dixit and Pindyck (1994) and Schwartz and Trigeorgis (2004) focuses on the value of an option to invest under uncertain benefits,

The concept of RO is empirically applied for ex-ante assessments of different agricultural investment, such as in irrigation systems (Carey and Zilberman, 2002, Michailidis, et al., 2009), ethanol plants (Pederson and Zou, 2009), and in precision agricultural machinery (Tozer, 2009). Under different considerations and assumption, different studies use MISTICs or similar RO approaches to evaluate GM crop breeding innovation. Wesseler, et al. (2007) calculate MISTICs for the cultivation of GM maize in Europe. For different countries and traits they find values between € 14.97/hectare and € 268.73/hectare. With a similar approach Demont, et al. (2004) conclude that a ban on GM sugar beet in the EU is correct, if EU households value the possibility of annual irreversible costs from that technology at minimum with € 1.1. Considering health aspects for Indian society from Golden Rice Wesseler and Zilberman (2014) apply RO to conclude that annual perceived costs from Golden Rice have to be at least USD 199 million per year to explain the current ban of the technology. However, the majority of existing literature on the economic assessment on GM crops takes an ex-post –after commercial introduction– perspective. Detailed analytical overviews about those ex-post studies are given by Barrows, et al. (2014), Carpenter (2013), Finger, et al. (2011), Klümper and Qaim (2014) and Zilberman, et al. (2010). Different to other major crops, no GM trait for wheat was ever commercialized and thus, GM wheat varieties are not content of current ex-post assessments. Existing studies on GM wheat analyse the potential economic welfare effect of GM herbicide tolerant (HT) wheat in Canada (Berwald, et al., 2006, Johnson, et al., 2005, Wilson, et al., 2008). The development of

[1] LEIBNIZ-INSTITUT FÜR PFLANZENGENETIK UND KULTURPFLANZENFORSCHUNG

high-yielding GM wheat is a very reasoned and promising breeding innovation and has not been analysed with an economic impact assessment so far.

For our model we make assumptions based on Saalbach, et al. (2014) and combine these with findings about the wheat cultivation situation in Germany. Within different scenarios we extent the model to potential CO_2 emissions savings and weighted those economically. Eventually we will derive MISTICs on three different scenarios, which will consider the potential private and social benefits and costs.

The paper proceeds as follows. The next section explains the motivation for scenario structure of benefits and costs, chosen for this study, and develops the theoretical concept of MISTICs. Thereafter data information is supplied, followed by the presentation of the results and their discussion. The final section summarizes our findings and suggests potential conclusions.

2 Model and Method

When an innovative technology is filed for deregulation, decision making bodies as the European Council and European Commission can either approve or decline the request. The objective in making such a decision should be to maximize society's welfare (V), which can be described as:

$$\max V = (0,\ W + J - I) \tag{1}$$

W are the discounted total future incremental[2] reversible net benefits, and J and I are the discounted total future irreversible benefits and costs associated with the deregulation of the technology, respectively. However, the determination of W, J and I is often challenging and sometimes unfeasible.

The net present value (NPV), as the standard neoclassical decision making criterion will suggest to deregulate an innovative technology if the expected social benefits are greater than the social costs. This approach neither considers uncertainty and irreversibility, nor the possibility to postpone the decision. In our model we use an ex-ante assessment model based on real options theory that explicitly considers these aspects.

The theoretical basis for our analysis is the real options approach by Dixit and Pindyck (1994). Based on this approach, we designed our economic assessment model as an information or decision making tool for politicians or decision making bodies. The output of our model will be a value for MISTICs, which then can be used as a decision criterion. We apply our conceptual framework to the situation where a seed company applies for deregulation of HOSUT wheat in the EU. Similarly to an option to invest in finance, decision making bodies can approve such an application immediately, or postpone the decision and wait for further information.

MISTICs are based on an American type of call option. In finance, an American call option gives the holder the right, but not the obligation to exercise an investment at any point in time. Our interpretation of the concept will be that the decision maker has the right, but not the obligation to authorize a new technology at any point in time. Further we assume that the option will never expire.

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[2] As "incremental" we consider the difference between HOSUT wheat and alternative conventional (non-GM) wheat.

Prior to the explanation of theoretical concept of MISTICs we will introduce the scenarios we use to compare and distinguish between reversible and irreversible incremental private and social benefits and cost.

2.1 Scenario I and II

We introduce three different scenarios (I, II.I and II.II), which will consider the potential benefits to wheat farmers and society, if the introduction of the new technology is combined with political conditions, i.e. decompensation areas (summarized in Table 1).

Table 1. *Scenario specification*

Scenario		0	I	II.I	II.II
Wheat variety		Certo	HOSUT	HOSUT	HOSUT
Decompensation for HOSUT wheat		–	–	+	+
Legumes cultivation on decompensation zone		–	–	–	+
Incremental benefits to farmer	Yield increase/ha	–	+	–	–
	Cost reduction (less cultivation cost/ha)	–	–	+	+
	Legumes (cost savings for N for next season)	–	–	–	+
Incremental benefits to society	Decompensation (reduced cultivation area)	–	–	+	+
	Legumes (CO_2 saving compared to synthetic N production)	–	–	–	+

Note: Scenario 0 represents conventional wheat production and is the reference for the percentage yield increase of HOSUT wheat. '+' indicates that the specification is included in the specific scenario.

Scenario I (constant area) only considers incremental benefit to wheat farmers due to yield increase on the area cultivated with HOSUT wheat. Scenario I is typical for first generation GM products, such as insect resistance and herbicide tolerant traits, where benefits are manly on the producer and not on the consumer side (Moschini and Lapan, 2006).

Scenario II (constant quantity) considers incremental benefits to society and cost reduction to farmers due to a decompensation of cultivation area. Green, et al. (2005) presented biodiversity advantages of decompensation areas in combination with high yield farming compared to low yield farming without decompensation area. Their findings supports the political idea of decompensation areas and indicates increasing biodiversity on decompensated areas as an additional non-private benefit. We assume that if HOSUT wheat is cultivated there will be a cultivation and a decompensation zone. The cultivation zone will be a percentage part of one hectare (ha) just as large that the absolute production in tons per ha of HOSUT wheat will be equal to the absolute production of one ha conventional wheat. The decompensation zone will be the remaining percentage part of one ha. In numbers, if HOSUT wheat has 28% higher yields per ha than conventional wheat, 0.78125 ha HOSUT cultivation zone is necessary to generate the same absolute yield as 1 ha conventional wheat crop. Consequently, 0.21875 ha are decompensation zone. Decompensation of agricultural production area does have different environmental benefits and by that it has a positive impact on social benefits. As benefits form decompensation we consider reduction in inputs, such as fertilizer, pesticides and fuel weighted by their CO_2 equivalent. Other benefits that might occur, such as increase in biodiversity are not considered. One can think about the scenario II as a regulation in order to transfer benefits of yield increasing GM technology to society. The decompensated land can either be not cultivated at all or with legumes, which would enrich the soil with nitrogen (N) for next year's crop. Therefore, we distinguish between scenario II.I with no cultivation and scenario II.II with legumes cultivation on the decompensated land.

2.2 Reversible and irreversible incremental private and social benefits and costs

It is important to distinguish between reversible and irreversible incremental private (farmer), non-private (non-farmer) and social (as the sum of private and non-private) benefits and costs. Reversible benefits or costs are those that stop if the farmer stops planting HOSUT wheat. E.g. increasing yield, less production costs per ha, and lower price per ton. Irreversible benefits or costs are those that still persist after HOSUT wheat is no longer cultivated. Following (Scatasta, et al., 2007) and (Demont, et al., 2004) we consider irreversible benefits as those resulting from reduced CO_2 emissions. Irreversible costs might be possible negative effects on biodiversity, transfer of genes from HOSUT wheat to bacteria or wild and conventional relatives, human health hazard, and biosafety regulation costs. Irreversibility implies that once an action is taken it is impossible to revert back to the initial situation as it was before the action. The possibility of irreversible costs to society associated with an introduction of GM crops is a major reason for the reluctant attitude towards GMOs in European society and politics.

The real options approach is of particular importance if the action is accompanied by irreversible costs. This is plausible, in so far, that if all costs that accompany an investment decision would be reversible, there would be no incentive to postpone the investment (provided that the immediate benefits exceed the costs), even if future benefits and costs are uncertain. Consequently, the presence of irreversibility reduces the benefits and gives a value to the possibility to postpone the decision and wait for the arrival of more information about the innovation's hazard (Arrow and Fisher, 1974).

We consider incremental benefits and costs for estimating the welfare effects. The incremental effect is determined by the difference between the benefits or costs from GM crops minus the benefits or costs of their non-GM alternative counterpart.

Table 2 summarizes the reversible and irreversible incremental private and social benefits and costs for HOSUT wheat production, which we accounted for or which are seen as irrelevant. Further it includes the symbols we will refer to throughout the text.

Table 2. *Scenario I and Scenario II: Incremental costs and benefits*

			Private (farmer) aspects	Non-private (non-farmer) aspects	Social	Symbol
Scenario I	Bene-fits/ha	Incremental irreversible	Irrelevant	Irrelevant	∑ (private + non-private) aspects	J
		Incremental reversible	Higher yield (28%)	Irrelevant		W (net benefits)
	Costs/ha	Incremental reversible	Lower price for less quality (lower protein content); higher absolute handling costs	Irrelevant		
		Incremental irreversible	Irrelevant	Possible negative effects for society		I
Scenario II	Benefits/ha	Incremental irreversible	Irrelevant	Input reduction due to decompensation	∑ (private + non-private) aspects	J
		Incremental reversible	Less cultivation cost; less fertilizer costs due to leg-umes cultivation (scenario II.II)	Irrelevant		W (net benefits)
	Costs/ha	Incremental reversible	Lower price for less quality (lower protein content); higher absolute handling costs	Irrelevant		
		Incremental irreversible	Irrelevant	Possible negative effects for society		I

2.3 Real options

The real options approach developed by Dixit and Pindyck (1994) is an extension of the classical net present value (NPV) decision criteria. Real options consider the optimal time to invest (irreversible) sunk costs (S) in return for uncertain infinite reversible net benefits of a project (W), given that W evolves according to a Geometric Browian Motion (GBM) as follows:

$$dW = aW\,dt + \sigma W\,dz \tag{2}$$

with

$$dz = \varepsilon_t \sqrt{dt}, \quad \varepsilon_t \approx N(0,\ 1) \tag{3}$$

where a is the drift rate, dt is the change over time, σ is the variance parameter and dz is the increment of a Wiener process. $dW = aW\,dt + \sigma W\,dz$ implies that the project's current value is known, but future values are log-normally distributed with a variance that grows linear over time (Schwartz and Trigeorgis, 2004).

2.4 Social reversible net benefits (W_T) and social incremental irreversible benefits (J_T)

W_T and J_T are calculated as the discounted sum of annual incremental reversible net benefits (w) and annual incremental irreversible benefits (w), respectively, from the time released (T) until infinity. The release of an innovation follows an adoption process. For agricultural crop innovations, the adoption process leads to an increase in the area allocated to the new variety over time.

2.4.1 Adoption

We assume that the adoption process follows an S-curve (Rogers, 2003) with the logistic form:

$$\theta(t)=\frac{\theta_{\max}}{(1+e^{-(a+bt)})} \tag{4}$$

The parameters a and b can be estimated with nonlinear optimization[3]. Where a is a constant, b is the rate of diffusion or adoption and $\theta_{\max}$ is the maximum level of adoption in percent.

2.4.2 Social reversible net benefits (W_T)

W_T are the social incremental reversible net benefits, which equals social incremental reversible benefits minus social incremental reversible costs.

$$W_T=\int_T^{\infty} w(t)\,e^{-\mu t}dt \tag{5}$$

where

$$w(t)=w_{\max}\theta(t) \tag{6}$$

with $w_{\max}$ being the maximum annual average aggregated reversible net benefit under complete adoption.

Social reversible net benefits for scenario I, II.I and II.II

For the descried scenarios we determine different total social reversible net benefits (W_T) with different social reversible net benefits per hectare (w_{ha}).

$$\begin{aligned} w_{ha_1} = {} & y_{conv.} * \iota_{HOSUT} * (p_{conv.} - \kappa_{HOSUT}\, p_{conv.}) - (\Delta h_{HOSUT}) - c_{wheat} \\ & -(y_{conv.} * p_{conv.} - c_{wheat}) \end{aligned} \tag{7}$$

with $y_{conv.}$ being the yield per ha of the conventional wheat variety, ι_{HOSUT} represents the yield increasing effect of HOSUT (1.28), $p_{conv.}$ being the price of the conventional wheat variety and κ_{HOSUT} represents the price reduction of HOSUT due to lower quality compared to the conventional wheat variety (0.05). Cultivation costs per ha of conventional wheat are considered by c_{wheat}. The values for $y_{conv.}$, $p_{conv.}$ and c_{wheat} are the three years average (from 2010 to 2013) y and p for German wheat producer. Further, increasing harvest cost per ha, that follow higher yield, are considered with Δh_{HOSUT} $(\Delta h_{HOSUT} = h_{HOSUT} - h_{conv.})$. With h_{HOSUT} being the harvest cost for wheat with a yield

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[3] Alternatively we estimated a und b with linear regression and received similar results.

level as we assume for HOSUT wheat and $h_{conv.}$ being the harvest cost for conventional wheat.

For scenario II.I

$$w_{ha_{II.I}} = \left((1-\lambda_{HOSUT})*y_{conv.}*\iota_{HOSUT}*(p_{conv.}-\kappa_{HOSUT}\ p_{conv.})-(\Delta h_{HOSUT})-c_{wheat}\right) \\ -(y_{conv.}*p_{conv.}-c_{wheat}) \tag{8}$$

with λ_{HOSUT} represents the land reduction factor (0.21875).

For scenario II.II

$$w_{ha_{II.II}} = w_{ha_{II.I}} + n_p \tag{9}$$

$$n_p = \lambda_{HOSUT}*(N_{legumes}p_N - c_{legumes} + c_{nitrogen_{application}}) \tag{10}$$

with $N_{legumes}$ being the amounted of fixed nitrogen (*N*) by legumes cultivation in kg per ha, p_N being the price for N per kg and $c_{legumes}$ being the cost of cultivation of legumes per ha. Further, the cost for the nitrogen application $(c_{nitrogen_{application}})$ by the end of the growing season, for preparing the next year crop, can be saved. The nitrogen effect (n_p) in scenario II.II includes impact of legumes cultivation on private and social benefits. For private benefits we consider that the farmer will produce N with the cost of legumes cultivation on the decompensation zone. Alternatively the farmer would buy synthetic *N*. Further the farmer can save N application costs on the area cultivated legumes. Thus, we account the quantity the farmer produces times the price of N minus the production cost plus the N application cost as annual private benefits.

2.4.3 Social irreversible benefits (J_T)

Similar to W, J can be determined as:

$$J_T = \int_T^{\infty} j(t)e^{-\mu t}dt \tag{11}$$

where

$$j(t) = j_{\max}\theta(t) \tag{12}$$

with $j_{\max}$ being the maximum annual average aggregated irreversible benefit under complete adoption.

Social irreversible benefits for scenario I, II.I and II.II

The social incremental annual irreversible benefits per ha (j_{ha}) are different within the scenarios as well . For scenario I no j_{ha} are considered and for scenario II.I $(j_{ha_{II.I}})$ and II.II $(j_{ha_{II.II}})$ they are approximated by:

$$j_{ha_{II.I}} = \chi\lambda_{HOSUT}g_{wheat} \tag{13}$$

$$j_{ha_{II.II}} = \chi(\lambda_{HOSUT}(g_{wheat} - g_{legumes} + \zeta N_{legumes})) \tag{15}$$

where χ represents external costs per ton CO_2 emissions, g_{wheat} and $g_{legumes}$ being the CO_2 equivalent per ha of wheat and legumes production, respectively, and ζ represents CO_2 equivalent in kg for the synthetic production of one kg N.

2.5 Maximum Incremental Social Tolerable Irreversible Costs (MISTICs)

Dixit and Pindyck (1994) showed that it is optimal to invest if W exceeds not only S but also the critical value $W^*(W > W^*)$, which can derived by including uncertainty through the hurdle rate $\left(\frac{\beta}{(\beta-1)}\right)$, which will be subsequently explained in more detail.

$$W^* = \frac{\beta}{(\beta-1)} S \tag{15}$$

Since $\beta > 1$, the hurdle rate increases the critical value for the investment decision (W^*) compared to a NPV investment decision criterion. An option to introduce HOSUT wheat should be exercised if W_T is at least W^*. If W_T is less than W^*, the decision should be postponed.

To introduce MISTICs we consider $S = I - J$. In the context of GM crops society in Europe is concerned about potential but uncertain irreversible cost. Albeit, the quantification of social irreversible cost (I), caused by the introduction of HOSUT wheat, seems to be unfeasible with our current state of knowledge. But we can resolve equation (16) in order to find a critical value for I (I^*).

$$I^* = \frac{\beta - 1}{\beta} W_T + J_T \tag{16}$$

The interpretation of equation (16) is that an option to introduce HOSUT wheat should be exercised if I is smaller than I^*. If I is larger than I^* the decision should be postponed. I^* is the real options decision criteria defined as MISTICs (Wesseler, et al., 2007). With MISTICs we identify the upper limit of the sum of irreversible social costs J_T and W_T, weighted by the hurdle rate, until it would be social optimal to immediate release an innovation (HOSUT wheat). Alternatively, if a technology is not released –as GM wheat– the MISTICs value can be seen as the benefits society is willing to sacrifice for the sake of not having this technology– GM wheat production.

2.6 Hurdle rate

The hurdle rate increases in accordance with the increasing volatility of previous gross margins, as we assume that past volatility makes future returns more risky and uncertain. We calculate the hurdle rate using average gross margins per ha for German wheat production from the years 2004–2013.

$$\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1 \tag{17}$$

where r is the risk free rate of return, δ the convenience yield and σ is the volatility of W_T. The convenience yield (δ) is the difference between the risk adjusted rate of return μ and the mean annual rate of return α (Dixit and Pindyck, 1994); this can be expressed as follows:

$$\delta = \mu - \alpha \tag{18}$$

The risk adjusted rate of return μ is calculated using the Capital Asset Pricing Model (CAPM) (Hull, 1999) The mean annual rate of return α can be determined following Mußhoff and Hirschauer (2003):

$$\alpha = \ln\left(\frac{\sum_{t=1}^{T} \frac{w_{ha_t}}{w_{ha_{t-1}}}}{n-1}\right) \tag{19}$$

where w_{ha} are the net incremental benefits per ha and year from the innovation in wheat production in Germany at time t.

The following flow chart visualizes the previous explain model calculation for the different scenarios.

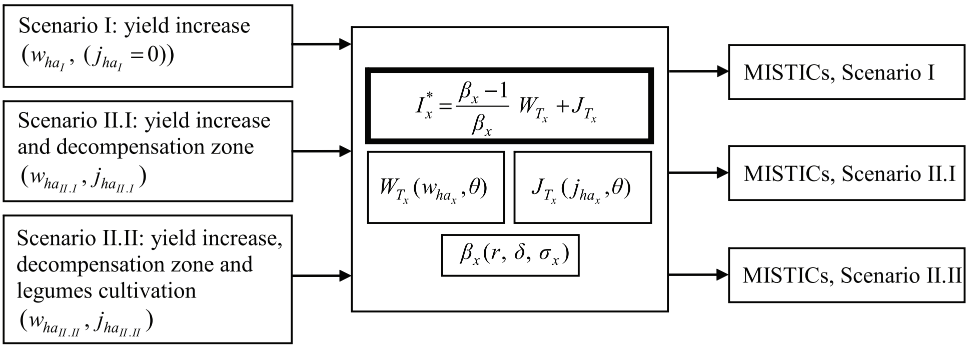

Figure 1. *Model calculation*

Note: x: scenario specific scenario; I_x^*: MISTICs; $\frac{\beta_x - 1}{\beta_x}$: hurdle rate; W_{T_x}: social reversible net benefits; J_{T_x}: Social irreversible benefits; w_{ha_x}: annual incremental irreversible benefits; j_{ha_x}: ocial incremental annual irreversible benefits per ha; θ: adoption rate; r: risk free rate of return; δ: convenience yield; σ: volatility of W_T.

3 Data

For the economic impact assessment we compare HOSUT wheat with conventional wheat production for the years 2006 to 2013. Our main assumption is that HOSUT wheat will have 28% higher yields compare to conventional wheat lines. The value corresponds to an average value found by Saalbach, et al. (2014), who compared HOSUT wheat lines with their conventional counterpart (Certo wheat lines) in micro-plot under field-like conditions in semi-controlled glass houses from the years 2009, 2010 and 2011. In this study we do not consider any potential market effects from the introduction of HOSUT wheat on the global wheat market. With the introduction of a GM based yield-increasing innovation markets are likely to be affected by increasing quantity but also by potential trading restrictions or segregation costs or non-GM premiums. However, the prices effect will have complex reasons and any assumption about resulting price impacts would be vague, which justifies our simplifying assumptions.

Further, we do not consider a seed premium for HOSUT wheat for two reasons. First, seed premiums are very different between crop, GM traits and growing country (Qaim, 2009). Second, the technologies used to create HOSUT wheat lines were published and is not protected by a patent. Thus, any prediction of a seed premium would be inaccurate. Also due to that we ignore potential benefits to the seed developers,

For private reversible net benefits (*W*) we calculated gross margin per ha and in total for German wheat farmers with data for production costs, yields, and prices from the KTBL[4] (KTBL, 2004, KTBL, 2006, KTBL, 2008, KTBL, 2010, KTBL, 2012), BMELV[5] (BMELV, 2015), DESTATIS[6] (DESTATIS, 2016) and LFL[7] (LFL, 2015). Here we assumed a 5% decrease in price for HOSUT wheat lines due to lower relative protein content (Saalbach, et al., 2014). With those information we constructed wheat farmers' gross margin time series and determine their volatility.

In scenario II.II we considered nitrogen fixing for legumes (trefoil) with a value of 200kg/ha/a. The price for nitrogen is determine buy the price of urea with a nitrogen content of 44–46% (USDA, 2014). Using the historical €/USD exchange rate (ECB, 2014) and assuming an average nitrogen content of 45% we calculated the price for pure

Table 3. *Wheat prices, yields and production costs per ha*

Year	Conv. wheat		Production cost (incl. cultivation and harvest costs in €/ha)			
	Price (€/t)	Yield (t/ha)	Conv. wheat	HOSUT wheat		
				Scen. I	Scen. II.I	Scen. II.II
2004	107.00	8.21	558.00	563.55	440.27	539.43
2005	96.00	7.51	597.71	609.22	475.95	570.55
2006	114.0	72.4	664.68	679.42	530.79	630.92
2007	179.0	6.99	681.85	698.41	545.63	644.45
2008	177.0	8.13	796.05	804.39	628.42	763.00
2009	123.0	7.84	875.10	886.83	692.83	824.96
2010	169.0	7.3	781.61	797.59	623.11	734.08
2011	215.0	7.06	848.74	866.25	676.75	786.59
2012	222.0	7.4	854.14	874.93	683.53	801.01
2013	206.0	8.03	863.40	875.52	684.00	808.35

Note: authors' calculation based on BMELV, DESTATIS, LFL, KTBL (see text)

4 Kuratorium für Technik und Bauwesen in der Landwirtschaft
5 Federal Ministry of Food and Agriculture (Germany)
6 Federal Statistical Office (Germany)
7 Bavarian State Research Center for Agriculture

N as fixed by legumes in €/ton. Based on that and considering the cost for N application (KTBL) we determined a legumes effect per ha (e.g. 10.28 €/ha in 2013). Prices, yield and scenario specific cost are summarized in Table 3.

As environmental impact and incremental irreversible non-private benefits (R) from the introduction of HOSUT wheat we consider saved CO_2 emissions due to decompensation zones in scenarios III and II.II. CO_2 emissions of 2.748 tCO_2/ha and of 0.7 tCO_2/ha for wheat and legumes cultivation, respectively, are derived using the ENZO2 Greenhouse Gas Calculator (ifeu, 2015). Further, we considered CO_2 emission from synthetic N production (ζ) with 5.88 $kgCO_2eq$/kgN (ifeu, 2015). CO_2 equivalent (χ) are economically evaluated with 65.18 €/tC following the literature review on social evaluation of carbon by Tol (2011). The results for R are presented in Table 4.

Table 4. *Annual incremental irreversible non-private (non-farmer) benefits per ha*

	Scen. II.I	Scen. II.II
In saved tCO_2/ha/a	0.39	0.24
In social €/ha/a	5.65	3.44

Source: authors' calculation based on ifeu (2015) and Tol (2011)

For the calculation of W and R we assume the total area allocated to wheat cultivation to stay constant at the average level from 2011–2013 (3 043 900 ha (DESTATIS, 2016)). The adoption of HOSUT wheat is assumed to follow the same pattern as for hybrid rape seeds in Germany for the period 1996–2012, which data are supplied by Kleffmann-Group (2012). For an accurate estimation of the adoption curve we must observe the actual situation. However, that is not possible in our case since neither HOSUT nor any other type of GM wheat ever got introduced to a commercial market before. To overcome this problem we estimate the adoption function with data for the adoption of hybrid rapeseeds in Germany. Even though HOSUT wheat and hybrid rapeseed differ due to their breeding technology and the crop species by using these data we can estimate an adoption function for a recent yield-increasing innovation[8] for the German agricultural crop market.

The annual net benefits and cost from now until infinity are discounted using the risk-adjusted rate of return (μ), derived using the capital asset pricing model (CAPM). For CAPM we included a riskless rate of return of 3.37% as the average interest rate from 2006 to 2013 for German 30-year federal bonds (Deutsche Bundesbank, 2014) and as a broad index, we used the average rate of return per ha for special crop farms in Germany from 2004 to 2013 (BMELV, 2015). The latter represents a diverse, risk reduced production or investment portfolio as opposed to broad index stocks, such as the S&P 500 or the DAX used in finance-based analysis. Eventually, all revenues and cost within the time series are deflated to the year 2013 (DESTATIS, 2014).

[8] Hybrid rapeseed were introduced to the German market in 1996

4 Results and discussion

In scenario I we determined MISTICs for 2014 to be € 1 029 mil. or € 12.78 per citizen or € 338,06 per ha cultivated with wheat (Table 5). Thus, an immediate introduction of HOSUT wheat in Germany in 2014 would have been economical if its actual incremental social irreversible costs (*I*) did not exceed this value. MISTICs for the other scenarios (as shown in Table 5) can be interpreted similar. However, within the decompensation scenarios II.I and II.II parts of the HOSUT wheat's benefits are shifted towards the non-private part of society (J_T). The share of non-private benefits are 3.85% and 4.64% in scenario II.I and II.II, respectively.

***Table 5**. MISTICs for scenario I, II.I, and II.II*

MISTICs in € (for 28% yield increasing wheat)	Society	Per citizen	Per ha cultivated with wheat	Share of non-private benefits in %
Scenario I	1029020955.85	12.78	338.06	0
Scenario II.I	623529014.32	7.75	204.85	3.85
Scenario II.II	653504506.83	8.12	214.69	4.64

Note: Maximum incremental social tolerable irreversible cost (MISTICs) for German society with a population of 80.5 mil. citizen (DESTATIS, 2014), and wheat cultivation area of 3.04 mil ha (DESTATIS, 2016).

The results in Table 5 are based on the hurdle rates 1.434, 1.029 and 1.053, for scenario I, II.I and II.I, respectively. A low hurdle rate indicates that an investment is more secure and thus it requires less insecure future return for being economical (equation (16)). The hurdle rate of 1.43 implies that, on average, every euro of social irreversible net cost needs to be matched by € 1.43 of social reversible net benefits to economical justify the authorization of HOUST lines.

Firstly, higher MISTICs in scenario I compared to scenario II.I and II.II are linked to the higher hurdle rate in scenario I. Secondly, however, also with a hurdle rate of one, and by that neglecting uncertainty and flexibility, total MISTICs of scenario I (€ 1 497 mil.) would be higher than in scenario II.I (€ 616 mil.) or scenario II (€ 656 mil.).

The quite low value of 3.85% and 4.64% as shares of non-private benefits in the scenarios II.I and II.II are due to quite low savings in N and CO_2 or their low monetary evaluation. This result indicates that HOSUT wheat, as a first generation GM crop, is mainly beneficial to farmers although a possible political regulation as decompensation zone would try to shift their benefits to the non-private society.

Throughout the calculation we assume a 28% yield increase based on trails under field-like trails in one location (Gatersleben, Germany). If HOSUT wheat would fails to increase yield by 28% but only 10%, MISTICs under scenario I would decrease to € 189 mil. in total and to € 2.35 per citizen. Such yield increases can be expected from the cultivation of wheat hybrids (Longin, et al., 2013). Hybridisation is seen as a conventional breeding method and wheat hybrids are currently adopted by German farmers. Applying our line of argumentation with MISTICs, hybrid wheat is deregulated since society does not associate incremental irreversible costs above € 2.35 per citizen with this technology. However, as conventional breeding is not associated with irreversible cots any convention breeding innovation with positive MISTICs is likely to be deregulated.

All MISTICs values are derived with a risk adjusted rate of return (μ) of 17.6% and an adoption patter, which can be expressed with Equation (4) as:

$$\theta(t) = \frac{0.84}{(1 + e^{-(-2.88 + 0.29t)})} \quad (20)$$

For the interpretation of the MISTICs values it important to consider that we did not account for any market price effect. Further, a yield-increasing innovation, as HOSUT wheat will also contribute to social benefits in terms of food security, especially in developing countries. Since that aspect is beyond the scope of our analysis, the derived MISTICs are likely underestimate the situation.

5 Conclusion

In this study we determined MISTICs for a yield increasing (28%) innovation in wheat production for Germany. When a new technology is developed for practical agricultural application decision makers have the opportunity to ban (or postpone the decision) or authorize its market introduction. Those decisions include irreversibility and uncertainty of expected benefits and costs to society and the option to wait for more information. The option to deregulate the innovation should only be exercised if the benefit of an immediate release outweighs those of keeping the option and postponing the decision, should the option to release be exercised. The suggested RO model, MISTICs, can be used for a monetary evaluation of the situation and to structure the decision finding process. Within the MISTICs approach we accounted for private benefits to farmers, non-private benefits uncertainty, flexibility and an adoption process. Further, we constructed the theoretical decompensation scenarios II.I and II.II. Even though, the practical implementation of these scenarios is rather unlikely they showed how pure private benefits of high-yielding GM wheat might be transferred to society. But also within the decompensation scenarios our results indicate low potential gains for the non-private society–the society's majority. In combination with the general reluctant attitude towards GMOs by European (European Commission, 2010) or German (forsa, 2014) societies that indicates low chances of an approval of GM wheat in Germany anytime soon.

With MISTICs we derive threshold values, limited to our assumptions, until which an immediate deregulation of GM HOSUT wheat will be social economical. The remaining challenge for decision-making bodies is to compare MISTICs with the actual irreversible costs (I) of GM HOSUT wheat. However, it might be unfeasible to produce a clear estimation for I with our current state of knowledge and it might even be zero. Eventually, since GM wheat seeds are not available in Germany one can conclude that currently society evaluates the potential irreversible costs of this technology to exceed MISTICs. But nevertheless, the option to deregulate HOSUT wheat will remain and decision can change with future information.

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