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HIGH YIELD GENETICALLY MODIFIED WHEAT IN GERMANY: SOCIO ECONOMIC ASSESSMENT OF ITS POTENTIAL

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Abstract

High Yield Genetically Modified Wheat (HOSUT) HOSUT lines are an innovation in wheat breeding based on genetic modification (GM) with an incremental yield potential of ca. 28 % compared to conventional wheat varieties. We apply the real option concept of Maximum Incremental Social Tolerable Irreversible Costs (MISTICs) to do an ex-ante assessment of the socioeconomic potential of HOSUT lines for Germany. We analyze the cost and benefits to farmer and society within two scenarios. Our results indicate that not authorizing HOSUT lines is correct if German society values the possible total irreversible costs of this technology to be € 10.44 and € 12.15 per citizen or more, depending on the scenario.

Keywords

Real option, wheat, yield increasing, uncertainty, irreversibility, social costs, GMO

1 Introduction

Transgenic crops or genetically modified organisms (GMOs) are one of the fasted adopted innovation in agriculture. Many innovations in transgenic crops offer potential benefits to farmers, but pose uncertain risks to society. However an adoption by farmers is only possible if transgenic varieties are deregulated by society's institutions (e.g. European Commission). The motivation of this research is the implicit regulatory challenge. Many studies have shown that different transgenic crops have cost saving or yield increase advantages compared to their conventional counterparts (CARPENTER and GIANESSI, 1999, QAIM, 2009, ZILBERMAN, et al., 2010). However, society's concerns about unknown health and environmental risks make GMOs a controversial topic and some states reject GMOs for their potential long term irreversible cost.
The total global production area of genetically modified (GM) crops increased from 1.7 mil. ha in 1996 to 175.3 mil. ha in 2013. Currently more than 30 different GM crops are commercially cultivated in 29 countries, primarily in North- and South America. Most of the currently cultivated GM crops are associated with first generation GM benefits such as insect resistance (IR) and herbicide tolerance (HT) (EVANS and BALLEN, 2013). The highest adoption GM traits is in soybeans where 79 % of the global annual production have either HT and/ or IR events. Soybean alone accounts for 48 % of the global GM crop production area (JAMES, 2013).

Wheat is the most important source for carbohydrate in human nutrition—20 % of the world's calorie and protein demand is met by wheat—which makes a stable and increasing wheat production crucial for food security (SHIFERAW, et al., 2013). In 2012 the global wheat production was ca. 670 mil. tons. The world biggest producers are China, India and the U.S.. Germany is with ca. 3 % of the global production the worlds' 9th greatest wheat producer (FAO, 2014). There have been numerous innovations in modern wheat breeding such as the application of the semi-dwarfing characteristic in the 1940s. Breeding technics have developed from weak forms of selection, to more precise selection in combination with mutation, inbred, hy-

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brid and biotechnology or genetically modified organism (GMO). However, only GMOs raise broad concerns across societies and therefore no developed GM wheat variety was ever commercialised.

Researchers from the IPK[2] in Gatersleben, Germany, used 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 are different HOSUT lines. Three of the HOSUT 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 wheat line Certo (SAALBACH et al., 2014). Such a yield increase corresponds to the actual national and global wheat yield development during the last 25 years (DESTATIS, 2015).

Independent from the state of development of HOSUT lines, the introduction of GM wheat lines into the European or German market seems to be very unlikely under the current social and political acceptance of GMOs. However, political decision about the support of research and development should be supported an economic assessment of the innovation's potential. In this study we will do a socio economic ex-ante assessment for the yield increasing potential of HOSUT lines for Germany. We will analyze the social economic potential of an intermediate release of HOSUT lines considering private and social reversible and irreversible costs and benefits and determine Maximum Incremental Social Tolerable Irreversible Costs (MISTICs) (DEMONT et al., 2004, WESSELER et al., 2007). The theoretical concept of MISTICs is based on the theory of real options. However, it differs from a 'classic' real option, which focuses on the value of an option to invest under uncertain benefits (MCDONALD and SIEGEL, 1987). MISTICs identify an upper bound for irreversible social costs where releasing or investing in a new technology is still economical.

We will apply MISTICs on three different scenarios, which will consider the potential private and social benefits and costs.

Previous studies about socio economic assessment of GMOs mostly targeted approved GM traits such as corn, soya and sugar beet, cotton (BROOKES and BARFOOT, 2012, DEMONT et al., 2004, KATHAGE and QAIM, 2012, QAIM and TRAXLER, 2005, WESSELER et al., 2007). Other studies dealt with the potential economic impact of herbicide tolerant (HT) wheat (BERWALD, et al., 2006, JOHNSON et al., 2005, WILSON et al., 2008). However, to the best of our knowledge so far no study dealt with socio economic assessment of high yield GM wheat.

The paper proceeds as follows. The next section motivated the application of a real options approach for our socio economic assessment, introduces the structure of considered scenarios 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 summarises our findings and suggests conclusions.

2 Theoretical Model and Method

During the approval process for an innovative technology, 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 maximise society's welfare (V), which can be described as:

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

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where W is the discounted total future incremental[3] net reversible 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.

Net present value (NPV), as the standard neoclassical decision-making criterion, suggest to deregulate an innovative technology if the expected social reversible net benefits exceeds the social irreversible net costs. However, this approach considers neither uncertainty and irreversibility nor the possibility of postponing 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 utilises the real option approach by DIXIT and PINDYCK (1994). Based on this approach, we designed a socio-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 model to the situation in which a seed company applies for deregulation of HOSUT lines in the EU.

Similar to financial investment options, decision-making bodies can approve such an application immediately or postpone the decision and wait for further information. The real option approach for MISTICs is based on an American type of call option, which gives the holder the right, but not the obligation, to exercise an investment at any point during the validity period. We interpret the concept such that the decision maker has the right, but not the obligation, to authorise a new technology at any point during an infinite validity period.

Before we will explain the theoretical concept of MISTICs we will introduce the scenarios we 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 but also non-farmers (i.e. the entire society). Benefits to the latter group are considered by decompensation areas as a political tool which could be linked to the introduction of the new technology. 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.

Scenario I (constant area) only considers incremental benefit to wheat farmers due to yield increase on the area cultivated with HOSUT lines instead of conventional wheat. Scenario I is typical for the assessment of first generation GM products, such as insect resistance and herbicide tolerant traits, where benefits are only on the producer (seed producer, farmer) and not on the consumer—or non-farmers—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. We assume that if HOSUT lines are 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 lines 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 lines have 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. Conse-

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

quently, 0.21875 ha are assigned as decompensation zone. Decompensation of agricultural production area does have different environmental benefits and by that it has a positive impact on society's welfare. 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 as shown in table 1.

Table 1: Scenario specification

Scenario		0	I	II.I	II.II
Variety		CERTO	HOSUT	HOSUT	HOSUT
Decompensation zone		-	-	+	+
Legumes cultivation on decompensation zone		-	-	-	+
Incremental benefits to farmer	Yield increase/ha	-	+	-	-
	Cost reduction (less cultivation cost/ha)	-	-	+	+
	Legumes cultivation (cost savings for N for next season)	-	-	-	+
Incremental benefits to society	Decompensation (less farm land cultivation)	-	-	+	+
	Legumes cultivation (CO_2 saving compared to synthetic N production)	-	-	-	+

2.2 Reversible and irreversible incremental private and social benefits and costs

It is important to distinguish between reversible and irreversible incremental benefits and costs, particularly in terms of private (farmer), non-private (non-farmer citizens) and social (the sum of private and non-private) aspects. Reversible benefits and costs are only present for the period during which the farmer cultivates HOSUT lines. Reversible benefits are defined as benefits of increasing yield, less production costs per ha, and lower price per ton. Conversely, irreversible benefits or costs are those that still persist even if HOSUT lines are no longer cultivated. We consider irreversible benefits as those resulting from reduced CO_2 emissions (DEMONT et al., 2004, SCATASTA et al., 2007). Irreversible costs might be related to possible negative effects on biodiversity, transfer of genes from HOSUT lines to bacteria or wild or conventional relatives, human health risk, and biosafety regulation costs. Irreversibility implies that once an action is taken, it is impossible to revert to the initial situation that prevailed before the action was taken. The possibility of irreversible costs for society following the introduction of GMOs in agriculture is a major reason for the reluctance in European society and politics to allow GMOs.

The real option approach is of particular importance if the action is accompanied by irreversible costs. This is plausible to the extent that if all costs accompanying an investment decision are reversible, there would be no incentives to postpone the investment (provided that the immediate benefits exceed the costs) even if future benefits and costs are uncertain. However, irreversibility reduces the benefits (ARROW and FISHER, 1974). Consequently, the presence of irreversibility gives a value to the possibility of postponing the decision and wait for further information regarding the risks posed by the particular innovation.

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 summarises the reversible and irreversible incremental private and social benefits and costs for HOSUT wheat production. Furthermore, we include the symbols used throughout the text.

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

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

2.3 Maximum Incremental Social Tolerable Irreversible Costs (MISTICs)

The real option approach developed by Dixit and Pindyck (1994) considers the optimal time to invest (irreversible) sunk costs (S) in return for uncertain infinite reversible benefits of a project (W), given that W evolves according to a Geometric Browian Motion (GBM). A GBM is a non stationary Markov process and consequently the prediction W_{t+1} only depends on W_t. A GBM can be written as:

$$dW = \alpha W dt + \sigma W dz \quad (2)$$

With

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

where α is the drift rate, dt is the change over time, σ is the variance parameter and dz is the increment of a Wiener process, which is independently and identically distributed according to a normal distribution with a mean of zero and a standard deviation of one. Equation (2) 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).
DIXIT and PINDYCK (1994) showed that it is optimal to invest if W exceeds not only S but also the critical value W^*, which can derived by including uncertainty through the hurdle rate ($\frac{\beta_1}{(\beta_1-1)}$), which will be subsequently explained in more detail.

$$W > W^* \quad (4)$$

$$W^* = \frac{\beta}{(\beta - 1)} S \quad (5)$$

As $\beta > 1$, the hurdle rate increases the critical value for the investment decision (W^*) compared with a classical investment decision criterion ($W_C^* = S$). An option to introduce HOSUT wheat should be exercised if W is at least W^*. If W is less than W^*, the decision should be postponed.
To introduce MISTICs we consider $S = I - J$ and formulate equation (5) as:

$$W^* = \frac{\beta}{(\beta - 1)} (I - J) \quad (6)$$

where the optimal W (W^*) is equal to the net incremental irreversible costs ($I - J$) weighted by the hurdle rate.

In the context of GM crops society in Europe is concerned about potential but uncertain irreversible cost. However, based on the current state of knowledge, quantifying the social irreversible costs (I) caused by introducing GM HT rapeseeds appears unfeasible. But we can resolve equation (6) to focus on the critical value for I (I^*).

$$I^* = \frac{\beta - 1}{\beta} W + J \quad (7)$$

The interpretation of equation (7) is that an option to introduce the HOSUT lines should be exercised if I is smaller than I^*. If I is larger than I^* the decision should be postponed. I^* is the real option decision criteria defined as MISTICs (WESSELER et al., 2007). With MISTICs we determine the upper limit of the sum of irreversible social costs (J) and reversible net benefits (W) weighted by the hurdle rate until it would be social optimal to immediate release an innovation (HOSUT lines). Or if a technology is not released (as GM wheat) the MISTICs value can be seen as benefits the society is willing to sacrifice for the sake of having not introducing GM wheat production.

2.4 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 $\left(\frac{\beta}{1-\beta}\right)$ using gross margins per ha for German wheat production from the years 2004-2013.

$$\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1 \quad (8)$$

where r is the risk free rate of return, δ the convenience yield and σ is the volatility of W. 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

$$\delta = \mu - \alpha \quad (9)$$

The risk adjusted rate of return (μ) is calculated using the capital asset pricing model (CAPM) with the formula:

$$\mu = r + [\mu_m - r] * \gamma_i \quad (10)$$

(COPELAND and COPELAND, 2003)

where $\boldsymbol{\mu_m}$ is the expected return on broad index of stock prices. The difference between the expected rate of return on the risky market and the risk-free investment ($[\boldsymbol{\mu_m} - \boldsymbol{r}]$), is called the market risk premium. $\boldsymbol{\gamma_i}$ is defined as the covariance between the rate of return of the project ($\boldsymbol{R_j}$) and the broad market ($\boldsymbol{R_m}$), divided by the variance of the broad market return

$$\gamma_i = \frac{\boldsymbol{COV(R_j, R_m)}}{\boldsymbol{VAR(R_m)}} \quad (11)$$

(COPELAND and COPELAND, 2003)

The mean annual rate of return α can be determined as follows MUßHOFF and HIRSCHAUER (2003):

$$\alpha = \ln\left(\frac{\sum_{t=1}^{T} \frac{w_{ha_t}}{w_{ha_{t-1}}}}{n-1}\right) * \frac{1}{\Delta t} \quad (12)$$

where w_{ha} are the net incremental benefits per ha and year from the innovation in wheat production in Germany at time t and Δt is the time interval between the observation points in years[4]. For t we consider the years from 2007 to 2013. and since we have annual time observation Δt is 1.

2.5 Social reversible net benefits (W_T) 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 that needs to be considered for our calculation of discount. For agricultural crop innovations, the adoption process leads to an increase in the area allocated to the new variety over time.

[4] The time intervals between our observation points is one year and therefore, $\Delta t = 1$. For monthly observation $\Delta t = 1/12$

2.5.1 Adoption

We assume that the adoption process follows an S-curve (GRILICHES, 1957, ROGERS, 2003) which can be formulated as

$$\theta(t) = \frac{\theta_{max}}{(1 + e^{-(a+bt)})} \qquad (13)$$

The parameters a and b can be estimated using nonlinear optimization[5], where a is a constant, b is the rate of adoption, as it measures the increase in adoption over time, $\theta(t)$ is the rate of adoption at time t and θ_{max} is the maximum level of adoption in percent. We assume that θ_{max} refers to the last year of observation with respect to the adoption data used.

2.5.2 Social reversible net benefits (W_T)

W_T is the social incremental reversible net benefit, which equals social incremental reversible benefits minus social incremental reversible costs. The total annual value of $[w(t)]$ under consideration of an adoption process is calculated as

$$w(t) = w_{max}\theta(t) \qquad (14)$$

with the maximum aggregated benefit under complete adoption (w_{max}) expressed as

$$w_{max} = w_{ha} * h \qquad (15)$$

where w_{ha} is the incremental reversible net benefits per ha and h represents the total area cultivated with wheat in Germany in ha.

The expected discounted present value of $w(t)$ from T until infinity (W_T) will be calculate as

$$W_T = \int_T^\infty w_i(t)e^{-\mu t}dt \qquad (16)$$

2.5.2.1 Scenario *I, II.I and II.II*

For the descried scenarios (see section 2.1) we determine different total social reversible net benefits (W_{T_j}) with different social reversible net benefits per hectare (w_{ha}).

For scenario I

$$w_{ha_I} = y_{conv.} * \iota_{HOSUT} * (p_{conv.} - \kappa_{HOSUT}p_{conv.}) - (\Delta h_{HOSUT}) - c_{wheat} - (y_{conv.} * p_{conv.} - c_{wheat}) \qquad (17)$$

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). The values for $y_{conv.}$ and $p_{conv.}$ 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 level as we assume for HOSUT lines and $h_{conv.}$ being the harvest cost for conventional wheat.

5 Alternatively we estimated a und b with linear regression and received similar results.

For scenario II.I

$$w_{ha_{II.I}} = (1-\lambda_{HOSUT})y_{conv.} * \iota_{HOSUT} * (p_{conv.} - \kappa_{HOSUT}p_{conv.}) - \left((1-\lambda_{HOSUT}) * \Delta h_{HOSUT}\right) - (1-\lambda_{HOSUT} * c_{wheat}) - (y_{conv.} * p_{conv.} - c_{wheat}) \quad (18)$$

$$w_{ha_{II.I}} = y_{conv.} * (p_{conv.} - \kappa_{HOSUT}p_{conv.}) + (\lambda_{HOSUT} * c_{wheat}) - (y_{conv.} * p_{conv.}) \quad (19)$$

With λ_{HOSUT} represents the land reduction factor (0.21875) and c_{wheat} being the cost of cultivation per ha of the conventional wheat variety.

For scenario II.II

$$w_{ha_{II.II}} = w_{ha_{II.I}} + n_p \quad (20)$$

$$n_p = \lambda_{HOSUT} * (N_{legumes}p_N - c_{legumes} + c_{nitrogen_{application}}) \quad (21)$$

$$w_{ha_{II.II}} = (1-\lambda_{HOSUT})y_{conv.} * \iota_{HOSUT} * (p_{conv.} - \kappa_{HOSUT}p_{conv.}) - \left((1-\lambda_{HOSUT}) * \Delta h_{HOSUT}\right) - (1-\lambda_{HOSUT} * c_{wheat}) + \left(\lambda_{HOSUT} * \left(N_{legumes}p_N - c_{legumes} + c_{nitrogen_{application}}\right)\right) - (y_{conv.} * p_{conv.} - c_{wheat}) \quad (22)$$

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 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. Alternatively the farmer would buy synthetic N. Further the farmer can save N application costs on the area cultivated legumes.

2.5.3 Social incremental irreversible benefits (*J*)

Similar to W we can determine J as:

$$J_T = \int_0^\infty j_{max}(t)\theta(t)e^{-\mu t}dt \quad (23)$$

$$r_{max} = r_{ha} * ha \quad (24)$$

2.5.3.1 Scenario *I, II.I and II.II*

The social incremental irreversible benefits per ha are different within the scenarios. For scenario I no social incremental irreversible benefits are considered. For scenario II.I and II.II the annual irreversible social benefits r per ha of HOSUT wheat are approximated by

$$r_{ha_{II.I}} = \chi\lambda_{HOSUT}g_{wheat} \quad (25)$$

$$r_{ha_{II.II}} = \chi(\lambda_{HOSUT}(g_{wheat} - g_{legumes}) + \lambda_{HOSUT}\zeta N_{legumes}) \quad (26)$$

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

3 Data

For the socio economic assessment we compare HOSUT lines with conventional wheat production for the years 2006 to 2013. Our main assumption is that HOSUT lines will have 28 % higher yields compare to conventional wheat lines. The value corresponds to an average value found by SAALBACH et al. (2014) with micro-plot under field-like conditions in semi-controlled glass houses from the years 2009, 2010 and 2011.

Germany only produces around 3 % of the annual global wheat crop (FAO, 2014). Therefore we do not consider that the increase in German wheat production due to an authorization of HOSUT lines may affect the world market price. Also, we assume that consumers are indifferent towards conventional and HOSUT wheat. Thus, the price for HOSUT wheat is assumed to be not different to the world market prices for wheat (of the same quality) and no trading restrictions or segregation costs or non GMO premiums are considered. In other words, we assume substantial equivalence and no market preferences for conventional wheat or wheat coming from HOSUT lines. Further, we do not consider any external impacts on the decision (e.g. import restrictions) of the rest of the world. To capture those type of effects our model can be linked to a market equilibrium model. We also assume that Germany will be the only country to adopt HOSUT. Since this scenario seems to be very much unlikely it requires some justification. HOSUT was developed by researcher of the IPK in Germany. Micro plot trials under field like condition have only been conducted in Gatersleben, Germany. The results of the field trials from 2009 to 2011 showed an average yield increase of 28 % compared to the non-transformed control wheat Certo. So far it was not tested how the plant characteristics differ under different climate conditions. Other climate condition in other regions might show different results. Over all we avoid assumptions that cannot be based on empirical evidences.

For private reversible benefits (W) we calculated gross margin per ha and in total for German wheat farmers with data for cultivation costs, yields, and prices from the KTBL[6], BMELV[7], DESTATIS[8] and LFL[9]. Hereby we assumed no differences in seed prices and a 5 % decrease in price for wheat from HOSUT lines (compared to conventional wheat price) due to lower relative protein content (SAALBACH, et al., 2014). Since the yield in HOSUT lines is higher the harvest cost will increase. Therefore we constructed a harvest cost function based on harvest cost for different yield levels from KTBL. Further, we assume that there will be no extra cost for HOSUT seeds. With those information we constructed gross margin time series, which allow us to determine volatility of wheat farmer's gross margin.

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

As environmental impact and incremental irreversible benefits (R) from the introduction of HOSUT lines we consider saved CO_2 emissions due to decompensation zones in Scenario II. CO_2 emission of 2.748 tCO_2/ha for wheat as well as for legumes cultivation of 0.7 tCO_2/ha is derived using is derived using the ENZO2 Greenhouse Gas Calculator (IFEU, 2014). For the

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7 Federal Ministry of Food and Agriculture (Germany)
8 Federal Statistical Office (Germany)
9 Bavarian State Research Center for Agriculture

social economic evaluation of the CO_2 equivalent (χ) we used 65.18 € per ton C following the literature review of peer reviewed literature on social evaluation of carbon by TOL (2011). We used the factor 0.2727 to convert tons (t) of $C\,O_2$ to tons of carbon (C) (EPA, 2004).

All revenues and cost within the time series R are deflated to the year 2013 (DESTATIS, 2014).

For the calculation of W and R we consider the three years average (2011-2013) for h (3,043,900 ha) and w_{ha} and r_{ha} (value depending on the scenario). The total area allocated to wheat cultivation is assumed to stay constant. Further we assume an adoption pattern as for hybrid rape seeds in Germany for the period 1996-2012 (KLEFFMANN-GROUP, 2012). The annual net benefits and cost from now until infinity are discounted using the risk-adjusted rate of return (μ), derived using the CAPM. For CAPM we included 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 to calculate μ_m and σ_m we used the average rate of return per ha for special crop farms in Germany from 2003 to 2013 (BMELV, 2014). Therefore, we assume this revenue level as the revenue to be achieved by an average crop farmer as the risk is decreased by a more diverse crop production portfolio. In comparison, in a finance-based analysis, broad index stocks such as S&P 500 or DAX are used to determine μ_m and σ_m.

4 Results and discussion

In scenario I we determined MISTICs for 2014 to be € 840.585 mil.. Thus, an immediate introduction of HOSUT lines in Germany in 2014 would have been economical if the actual social irreversible costs (I) did not exceed this value. MISTICs for 2014 per ha cultivated with wheat[10] and per citizen are € 654.72 and € 10.44, respectively. The MISTICs for the other scenarios (as shown in Table) can be interpreted the same way. In scenario II.I and II.II we shifted the benefits partly towards the non-private part of society. That part is represented by R within equation (7) and accounts for 3.53 % and 4.24 % in scenario II.I and II.II, respectively, of the total MISTICs.

Table 3: MISTICs for scenario I, II.I, and II.II

MISTICs in €	Society	Per citizen	Per ha wheat	Share of non-private benefits in %
Scenario I	840585435.84	10.44	654.72	0
Scenario II.I	926530828.87	11.51	749.12	3.53
Scenario II.II	978024972.33	12.15	788.96	4.24

Note: Maximum incremental social tolerable irreversible cost (MISTICs) for German society with a population of 80.5 mil. citizen (DESTATIS, 2014), and rapeseed cultivation area of 1.47 mil ha.

For the results it is important to consider the different hurdle rates we received for each scenario. The hurdle rates for scenario I and II are 1.94 and 1.07, respectively. Therefore, we can conclude that the benefits from scenario I are more insecure compared to those in scenario II. The hurdle rate of 1.94 implies that, on average, every euro of social irreversible net cost has to be matched by about € 1.94 of social reversible net benefits to economical justify the au-

[10] Refers to one single ha, that will be cultivated with wheat every second year

thorization of HOUST lines. Higher MISTICs in scenario II.I and II.II compared to scenario I are linked to the higher hurdle rate in scenario I[11]. Without the hurdle rate, and by that neglecting uncertainty and flexibility, the total maximal social irreversible cost of scenario I (€ 1 647 mil.) are higher than in scenario II.I (€ 994 mil.). A low hurdle rate indicates that an investment is more secure and thus it requires less insecure return for being economical (equation (6)).

Decision making bodies can use MISTICs as a decision criteria. With the objective to maximise society's welfare, HOSUT lines should be immediate released if MISTICs are smaller than actual I or if the benefits from an immediate release outweighs those of the option to release. However, it is unfeasible to produce an estimation for I with our current state of knowledge. If I is zero or there is final proof that HOSUT lines do not have any negative effect on environment or human health then the MISTICs value are pure costs the society bears from rejecting the innovation.

The quite low value of 3.53 % and 4.24 % 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 the introduction of HOSUT lines will be mainly beneficial to farmers although a possible political regulation as decompensation zone can shift benefits to the non-private society.

All MISTICs values are calculated with a risk adjusted rate of return (μ) of 17.6 % and an adoption function of the form:

$$\theta(t) = \frac{0.84}{(1 + e^{-(-2.88+0.29t)})} \qquad (27)$$

5 Conclusion

When a new technology is developed for practical agricultural application decision makers have the opportunity to ban (or postpone the decision) or authorise its market introduction. Those decisions include irreversibility and uncertainty of expected benefits and costs to society and the option to wait for more information. Only if the benefit of an immediate release outweighs those of keeping the option and postponing the decision, the option to release should be exercised. MISTICs can be used for a monetary evaluation of the situation and to structure the decision finding process.

An increase of wheat yield by 28% per ha would have accounted for 406.60 €/ha/a incremental reversible private benefits, on average during the period 2006-2013, for German wheat growers. However, this results give only limited information for a socio economic evaluation. MISTICs include the private benefits to farmers, non-private benefits, uncertainty, flexibility and an adoption process. Further, with the scenarios II.I and II.II we showed how pure private benefits might be transferred to society. Our results show MISTICs for German citizens between € 10.44 and € 12.15 The quite low MISTICs in combination with consumer's negative attitude towards GMO (EUROPEAN COMMISSION, 2010) indicates conflicts of interest and a low political chance for an approval of HOSUT lines in the near future. Further, the benefit from the introduction of HOSUT lines will be only (scenario I) or mainly (scenario II) with the famers. However, with a regulation as suggested within scenario II the benefits of the innovation are partly transferred to the non-private part of society's incremental benefit. Still, the non-private borne share of MISTICs is quite small with 3.53 % and 4.24 % but the distribution of private to non-private benefits might influence the citizen's attitude and political choice as well. Nevertheless, if HOSUT lines would be globally adopted one can expect decreasing prices as well as increasing food security as benefits to society. However, it is un-

[11] Note: MISTICs are calculated by the inverse of the hurdle rate (equation (7))

clear how high the actual yield increase will be and how the innovation will disseminate and substitute other crops.

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