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A Critical Assessment of Methods for Analysis of Social Welfare Impacts of Genetically Modified Crops:
a Literature Survey

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A Critical Assessment of Methods for Analysis of Social Welfare Impacts of Genetically Modified Crops: a Literature Survey

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Abstract

This paper is a review of existing literature on economic and environmental costs and benefits of genetically modified (GM) crops focusing on methodological issues arising from this literature. Particular attention is given to the production function framework commonly used to quantify costs and benefits of GM crops at the farm level and to equilibrium displacement models used to quantify impacts of GM crops on social welfare. Methods are discussed with respect to their sensitivity to specific parameter values and key areas are identified for further research.

Keywords: social welfare impacts, farm level impacts, GM crops, survey, real options.

1. Introduction: Purpose of This Study

This paper is a review of existing literature and contributes to the ongoing discussion about social welfare impacts of genetically modified (GM) crops by focusing on methodological issues arising from this literature.

Five issues are of particular interest. The first issue relates to producer welfare and addresses the use of a production function framework to quantify costs and benefits of GM crops at the farm level. The second issue also relates to producer welfare and addresses the equilibrium displacement models used to quantify impacts of GM crops on producer welfare. The third issue relates to consumer welfare and addresses the relationship between consumer and producer welfare impact studies. The fourth issue relates to external social welfare impact studies and addresses methodologies used to identify and quantify impacts on the environment that are not captured by market dynamics. The fifth issue relates to methodologies used to identify and quantify administration costs of different regulatory frameworks and the costs to create proper infrastructure to foster and manage the adoption of GM crops.

With respect to the first issue we note that, in the case of pesticides, several authors have shown that analyzing farm level costs and benefits of a pest control management system in a production function framework suffers several limitations and may lead to significant overestimation of the benefits of such a system (see Lichtenberg and Zilberman, 1986, Babcock et al., 1992, Rola and Pingali, 1993, Chambers and Lichtenberg, 1994, Carpentier and Weaver, 1997, Saha et al., 1997, Waibel and Fleischer, 1998, Zadocks and Waibel, 2000). In this paper we offer a critical assessment of studies using the production function framework.

With respect to the second issue, we note that authors base quantification of producer welfare impacts of GM crops on changes in farm profits or on one of four equilibrium displacement models proposed by Alston et al. (1995), Moschini and Lapan (1997), Moschini et al. (2000), and Falck-Zepeda et al. (2000). The results provided by those models have limitations due to some of the required assumptions and the data used for calibration (see Barkley, 2002, Demont et al., 2004).

With respect to the third issue we notice that several authors such as Boccaletti and Moro (2000), Chen and Chern (2002), Kaneko and Chern (2003), Chern et al. (2003) suggest that consumer acceptance of GM food products may be an important issue in the quantification of social welfare impacts of GM crops. Yet, most social welfare impact studies of GM crops still fail to recognize this issue, assuming no shifts in the overall demand function nor assuming a separate demand function for GM food products.

With respect to the fourth issue we notice that there is a lack of economic studies trying to quantify long term environmental impacts of GM crops. Social welfare impact studies, furthermore, focus on pesticide use to quantify environmental impacts. Other impacts such as effects on non-target organisms, changes in genetic diversity, impacts on soil erosion and moisture retention, development of resistance, are often not quantified in economic terms and left out of the social welfare function.

With respect to the fifth issue we notice that costs associated to the creation and administration of an appropriate regulatory framework and infrastructure for the release of GM crops into the environment are rarely quantified. These costs may be important, especially in developing countries, and should be included in the social welfare function.

Our critical assessment focuses especially on the first and second issue and is structured as follows. In section two we review existing social welfare impact studies, presenting seven basic models commonly used in the literature. In section three we offer a critical assessment of social welfare impact studies and discuss specific methodological issues such as the choice of demand and supply elasticity (3.1), measurement issues related to farm level gross margins (3.2), aggregating issues (3.3), issues related to potential long-term environmental impacts (3.4). Section four summarizes our main findings and concludes.

Our review by no means covers all studies that have been done on the economics of transgenic crops, but we believe that we have covered the main approaches being used.

2. Impact of GM Crops on Social Welfare: Theory

In this section we describe the basic economic surplus models that are used in the literature to investigate social welfare impacts of transgenic crops. The economic surplus approach is a well established approach in the economic literature (see for example Griliches, 1958; Peterson, 1967; Schmitz and Seckler, 1970; Davis et al. 1987; and Norton et al. ,1987).

Following Harberger (1971), the economic surplus approach is based on three main postulates:

1. The competitive demand price for a given unit measures the value of that unit to the demander;
2. The competitive supply price for a given unit measures the value of that unit to the supplier;
3. When evaluating the net benefits or costs of a given action, the costs and benefits accruing to each member of the relevant group should be added without regard to the individual(s) to whom they accrue.

The third postulate, in particular, requires the compensation principle to hold, i.e., transfer from "winners" to "losers" can be made in a lump-sum fashion without any tax-induced distortions. This means that this approach does not consider any distributional issues. Only some interrelationships between products and factor markets, namely those directly impacted by the technological change, are considered. Transaction costs arising from imperfect information and risk are included only implicitly through the pricing system.

Yet, following Alston et al. (1995): "[Imperfect information] can lead to incomplete risk markets, in which case competitive equilibrium is no longer *Pareto Optimal*… A conventional welfare analysis that ignores transaction costs will provide results that overstate the benefits of activities with high transactions costs both absolutely and relative to activities with relatively low transaction costs." (p. 51-52) [2]

Keeping the limitations of the economic surplus approach in our mind we now proceed with a brief overview of the basic economic surplus models used in the literature to evaluate social welfare impacts of transgenic crops. A summary of the models discussed and some of their characteristics are presented in Table 1.

Model 0: The Change in Revenue Method

This model approximates changes in producer surplus with changes in gross margins per acre at farm level, given by the difference between revenues and variable production costs, multiplied by the

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[2] For a more detailed review of the basic criticism of the economic surplus approach see Alston et al. (1998), p. 43 – 53.

acreage, or extent of adoption. The impact of genetically engineered crops on revenues is investigated through impacts on yields. The impact on variable costs is investigated through impacts on costs for seeds, technology, and crop protection.

Examples of this line of work are offered by Brookes (2003a, b), Carpenter and Gianessi (2001), Thirtle et al. (2003). Brookes (2003a) investigate *ex post* farmer welfare impacts of Bt corn in Spain in 2002. The author finds a positive impact of about \$21 million based on the assumptions of high European corn borer infestation and an adoption rate of 36%. Brookes (2003b) analyzes *ex ante* welfare impacts of RR soybeans in Romania in 2003, finding a positive impact of about \$7 million. Carpenter and Gianessi (2001) investigate ex-post farm welfare impacts of Bt corn, Bt cotton, and RR soybeans in the U.S. in 1998 and 1999. The authors find a negative impact in the order of \$31 million for Bt corn and a positive impact in the order of \$96 million for Bt cotton and \$218 million for RR soybeans annually.[3] Thirtle et al. (2003) investigate *ex ante* farmer welfare impacts of Bt cotton in South Africa and find a potential positive impact of \$ 60 million, assuming an adoption rate of 100%.[4] Other studies include Pray et al. (2001, 2002) for Bt cotton in China, Ismaël et al. (2003) for Bt cotton in South-Africa and Qaim (2003) and Qaim and Zilberman (2003) for Bt cotton in India

The change in revenue approach does not consider aggregate effects and therefore does not consider impacts on consumer welfare. Furthermore, as noted in Frisvold et al. (2003), changes in net revenues approximate changes in producer surplus only when the country taken into consideration is small (i.e. it faces a perfectly elastic demand) and the supply function is highly inelastic. A more theoretically consistent approach is proposed by Alston et al.(1995).

Model 1: Alston et al. (1995)

Closed Economy Model (without technology spillovers and IPR[5] rents)

For empirical applications, Alston et al. (1995) propose a model where demand and supply functions are assumed to be linearly dependent on price.[6] Agricultural technology innovations, such as

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[3] Annual averages based on values in Carpenter and Gianessi (Table 2).

[4] In this article we noticed a computational error. The authors state the number of hectare planted with cotton in Africa is about 2.5 million. The estimated gains of 250 Rand per hectare would give a total gain of 600 million Rand and not 6 billion Rand as stated by the author. Using the exchange rate suggested by the author of 10 Rand for 1 U.S. dollar, total gains are equal to \$60 million and not \$600 million as stated by the authors (see p.731).

[5] Intellectual Property Rights.

transgenic crops act as a supply shifter. The equilibrium price is found at the point where demand equals supply. Figure 1 shows a graphical representation of the economic surplus model or basic market equilibrium displacement model in its simplest form.

In this partial equilibrium framework the impact of technology on consumer surplus is given by the area P_0abP_1. The impact of technology on producer surplus is given by the area *cfbd* minus area P_0afP_1. The change in social welfare is given by area *cabd.* In order to quantify these areas, researchers need to know the value of demand and supply own price elasticities ($\eta = \left(dQ^D/Q\right)\big/\left(dP/P\right)$ for demand and $\varepsilon = \left(dQ^S/Q\right)\big/\left(dP/P\right)$ for supply), and need to acquire (or simulate) data on market price and quantity with and without biotechnology.[7]

Social welfare impacts are based on the following system of demand and supply functions:

$$(4)\ \begin{cases} Q^S = \alpha + \beta(P+k) \\ Q^D = \gamma - \mu P \end{cases}$$

The change in consumer surplus, area P_0abP_1, is given by $\Delta CS = P_0Q_0Z(1+0.5Z\eta)$, where $Z = K\varepsilon/(\varepsilon+\eta)$ and *k* is the vertical shift of the supply function expressed as a proportion of the initial price, $K = (P_0 - k)/P_0$, Q_0 is the quantity that would have been marketed in the year analyzed had transgenic crops not been available. The change in producer surplus, area *cfbd* minus area P_0afP_1, is given by $\Delta PS = P_0Q_0(K-Z)(1+0.5Z\eta)$. The change in social welfare, area *cabd*, is given by the sum of changes in consumer and producer surplus as $\Delta SW = \Delta PS + \Delta CS = P_0Q_0K(1+0.5Z\eta)$.

At any point in time *t* the percentage yield improvement can be converted in a cost reduction by dividing it by the supply elasticity. The percentage downward supply shift factor, K_t, can be calculated as $K_t = \left[\left(\Delta Q/\varepsilon Q\right) - \left(\Delta C/C\right)/(1+\Delta Q/Q)\right]p\theta_t(1-\delta_t)$, where $\Delta C/C$ is the percentage cost reduction per hectare and $\Delta Q/Q$ is the percentage yield improvement due to biotechnology, *p* is

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[6] It should be noticed that although linear demand functions are often used in empirical social welfare impacts studies for transgenic crops, they do not derive from any of the consumer utility functions typically used in theoretical studies and depart from modern practice in empirical demand analysis, which fosters the use of flexible functional forms (see Dhar and Foltz, 2005).

[7] Q^D represents quantity demanded, and Q^S represents quantity supplied. They will be equal at the equilibrium.

the probability of success of biotechnology, θ_t is the adoption rate of transgenic crops, and δ_t is the annual rate of depreciation of biotechnology.

The authors suggest that when there are insufficient resources to obtain an estimate of $\Delta Q/\varepsilon Q$, existing literature would justify the assumption of the supply elasticity being one, just for this step. It is also possible to show that measures of welfare impacts do not vary significantly with the functional form chosen to model demand and supply. Welfare impact measures are instead very sensitive to the values of elasticity of demand and supply.

Calibration of this model requires data on market price and quantities for the specific crop, biotechnology adoption rate, average cost reduction per land unit due to biotechnology, average yield improvement per land unit due to biotechnology, technology sellers' price, supply elasticity, and demand elasticity.

An empirical application is offered by Qaim (1999) who investigates ex-ante social welfare impacts of virus resistant potatoes in Mexico. The model runs from 1991 to 2015 and extrapolating the actual situation in 1996, the author finds a positive impact on social welfare of at least \$7.2 million. Of this amount, 83.2% accrues to farmers and 16.8% to consumers.[8] The closed economy model strictly refers to homogenous products sold in a single market and does not allow for the existence of multiple markets, which is representative for the case Qaim (1999) analyzed. To consider this latter case Alston, et al. (1995) propose a second model: the open economy model.

Model 2: Alston et al. (1995)

Small/Large Open economy model (without technology spillovers and IPR rents).

In this model two regions are taken into consideration: the innovating region (A) and the rest of the world (ROW). Social welfare impacts are based on the following system of demand and supply functions:

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[8] These figures refer to scenario 1 in Qaim (1999).

$$(5)\begin{cases} Q_A^S = \alpha_A + \beta_A(P+k\ ) \\ Q_A^D = \gamma_A - \mu_A P \\ Q_{ROW}^S = \alpha_{ROW} + \beta_{ROW}P \\ Q_{ROW}^D = \gamma_{ROW} - \mu_{ROW}P \end{cases}$$

The change in consumer surplus in region A is given by $\Delta C\mathrm{S}_\mathrm{A} = \mathrm{P}_0\mathrm{Q}_{\mathrm{A}0}^{\mathrm{D}}Z(1{+}0.5Z\eta_A)$ where $Z = K\varepsilon_A / \left[\varepsilon_A{+}\mathrm{s}_\mathrm{A}\eta_A{+}(1\text{-}\ \mathrm{s}_\mathrm{A})\eta_{ROW}^E\right]$. K is again the vertical shift of the supply function expressed as a proportion of the initial price, $K = (P_0 - k)/P_0$, and can be computed as in the closed economy model; s_A is the fraction of product consumed in region A, and $\eta_{ROW}^E = \left(\beta_{ROW} + \mu_{ROW}\right)P_0 / \left(Q_{ROW}^D - Q_{ROW}^S\right)$ is the excess demand elasticity.[9] The change in producer surplus in region A is given by $\Delta P\mathrm{S}_\mathrm{A} = \mathrm{P}_0\mathrm{Q}_{\mathrm{A}0}^{\mathrm{S}}(K - Z)(1{+}0.5\mathrm{Z}\varepsilon_A)$. The impact on social welfare in region A will be given by the sum of changes in consumer and producer surplus in region A. The impact on social welfare in the rest of the world is given by $\Delta SW_{\mathrm{ROW}} = \mathrm{P}_0\left(\mathrm{Q}_{\mathrm{ROW}0}^{\mathrm{S}} - \mathrm{Q}_{\mathrm{ROW}0}^{\mathrm{D}}\right)Z(1{+}0.5\mathrm{Z}\eta_{\mathrm{ROW}})$.

Alston et al. (1995) note that if region A is small it will not be able to influence the product price P which will equal the world price P_w. Region A will face a perfectly elastic demand function ($\eta \to \infty$) and there will be no change in consumer surplus. Social welfare impacts in the small open economy case are equal to changes in producer surplus and can be computed as $\Delta SW = \Delta PS\ =\ P_w Q_0 K(1 + 0.5K\varepsilon)$, where P_w is the world price. Note that this model does not consider the possibility of technology spillovers into the rest of the world. With respect to the general social welfare function presented in equation (1), in this model $\Delta P\mathrm{S}$ represents changes in Π, and $\Delta C\mathrm{S}$ represents changes in CW.

For each region considered, calibration of this model requires data on market price and quantities for the specific crop, biotechnology adoption rate, average cost reduction per unit of land due to biotechnology, average yield improvement per unit of land due to biotechnology, technology

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[9] At the equilibrium we will have that $Q_A^D + Q_{ROW}^D = Q_A^S + Q_{ROW}^S$.

sellers price markup, the farm supply elasticity and the consumer demand elasticity (only in the large economy case).

The open economy model of Alston et al. (1995) can be extended to a multi-product, multi-region model. Functional forms for demand and supply function can be chosen to be non-linear. An empirical application based on the extended model is offered by Frisvold et al. (2003) who consider a multi-product and multi-region model with a truncated log-linear specification of the supply function. The authors calibrate the model with agricultural production data from 1989 and assume that genetic improvement causes yield gains equal to half of observed yield gains from 1975 to 1992. The authors include in the social welfare function not only consumer and farmer welfare, but also government payments and quota rents due to government intervention and possible trade restrictions such as tariffs. The following crops are analyzed: wheat, corn, coarse grains, soybeans and cotton; in the following regions: the U.S., Canada, the E.U., other western European countries, Japan, Australia/New Zealand, China/transitional economies, developing agricultural exporters, developing agricultural importers and the rest of the world.

Based on data from 1975 to 1992, the model predicts a total yearly impact on world social welfare of biotechnology equal to \$590 million (in 1989 US Dollars) distributed as follows: \$954 million to consumers, -\$347 million to producers, \$32 million in government payments, and \$15 million in quota rents. In particular, producers in developed countries gain \$9 million, while producers in developing countries and transitional economies loose \$356 million. The country with highest gains is the U.S. with \$162 million to producers, \$223 million to consumers, \$25 million in government payments and \$1 million in quota rents.[10]

The output market measures of social welfare, such as those offered by the models from Alston et al. (1995), do not allow capturing monopoly rents from IPR’s owned by technology sellers. IPR rents occur, for example, through licensing agreements requiring the payment of a technology fee. In 1997 Moschini and Lapan notice that the conventional assumption of competitive input markets did not hold any longer. To take IPR rents into consideration the authors develop an alternative approach by measuring social welfare impacts in the input market.

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[10] Government payments enter the social welfare function with a negative sign.

Model 3: Moschini and Lapan (1997)

Closed economy model (without technology spillovers but including IPR rents)[11]

Moschini and Lapan's (1997) approach relates conventional and innovated input use (in our case conventional and genetically engineered seed use) through the use of efficiency units. This allows the more productive factor to be measured in the same physical units as the less productive factor. Let x_0 represent conventional seed quantities, x_1 genetically engineered seed quantities, $\hat{x}_1 = \delta x_1$ the genetically engineered seed quantities expressed in terms of efficiency units, $\delta > 1$ is an efficiency conversion factor such that $g\left(x_1, k\right) = f\left(\delta x_1, k\right)$, where g is the production function for the conventional technology and f is the production function for biotechnology, and k represents other inputs to production.

The parametric specification of the indirect farmer profit function is given as $\Pi\left(p, \hat{w}, r\right) = Ap^{1+\varepsilon}\left[s_x \hat{w}^{1-\sigma} + r^{1-\sigma}\right]^{-\left[\varepsilon/(1-\sigma)\right]}$, where A is a scaling parameter, p is product price, $\hat{w}$ is the cost of genetically engineered seeds expressed in efficiency units, r is the cost of the other inputs to production, s_x is the share of seed costs to total costs, σ is the elasticity of substitution between seeds and other inputs to production. Consumer demand can be represented as $Q^D = Bp^{-\eta}$, where B is a scaling parameter. From the indirect profit function and the consumer demand function, Moschini and Lapan (1997) obtain the technology seller derived demand for genetically engineered seeds $\chi\left(\hat{w}\right) = x\left(p\left(\hat{w}, r\right), \hat{w}, r\right)$.

Social welfare impacts are obtained in the market for seeds as $\Delta SW = \int_{\hat{w}_1^M}^{c} \chi\left(\hat{w}\right) d\hat{w} + \left(\hat{w}_1^M - c/\delta\right)\hat{x}_1^*$ where $\hat{w}_1^M$ is the price in efficiency units set by technology sellers for genetically engineered seeds and it is lower or equal to the price of conventional seeds, c is the marginal cost of production of genetically engineered seeds, and $\hat{x}_1^*$ is the quantity of genetically engineered seeds that maximizes technology sellers profits. With respect to the model presented in

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[11] We present here the case of a drastic innovation.

section 2, $\int_{\hat{w}_1^M}^{c} \chi\left(\hat{w}\right) d\hat{w}$ represents the sum of impacts on farmers and consumer surplus, i.e. changes in CW and part of changes in Π (equation (1)). The remaining variation in Π is explained by $\left(\hat{w}_1^M - c/\delta\right)\hat{x}_1^*$, which represents welfare impacts for technology sellers.

Calibration of this model requires data on market price and quantities for the specific crop;; average cost reduction per unit of land due to biotechnology, average yield improvement per unit of land due to biotechnology, technology sellers' price markup, the supply elasticity, the demand elasticity and the elasticity of substitution between seeds and other inputs to production.

Model 4: Moschini et al. (2000) NLCE Model (Non Linear Constant Elasticity)

Large open economy model without technology spillovers and IPR rents

Moschini et al. (2000) extend the closed economy model to an open economy model with three regions. To make the model empirically tractable, the authors assume that farmer derived demand for genetically engineered seed is proportional to the number of acres planted with those seeds, i.e. the amount of seed per acre is assumed constant. The number of acres supplied to a specific crop, *L*, varies and is endogenous to the model. Social welfare impacts, therefore, are no longer calculated in the market for seeds, as in model 3, but in the market for land allocated to the crop in question.

The parametric specification of the indirect farmer profit function in model 4 is slightly different than in model 3: $\Pi = A + \phi + \left[p^{1+\varepsilon}(1+\Delta Q/Q)r/(1+\varepsilon)\right] - vw(1+m)$, where ϕ is the coefficient of unit profit increase due to biotechnology, v is the amount of seeds per acre, w is the price of genetically engineered seeds and m is the technology seller markup on seed price. For a given adoption rate θ the average profit per acre associated to a specific crop is given by $\overline{\Pi} = A + \theta\phi + \left[p^{1+\varepsilon}(1+\theta\Delta Q/Q)r/(1+\varepsilon)\right] - vw(1+\theta m)$. The average profit per acre determines the land supply function for the specific crop: $L = C\overline{\Pi}^{\varphi}$, where C is a scaling parameter and φ is the elasticity of land supply with respect to profits per acre. The land supply function determines the supply function for the specific crop. This structure holds in each region of the model. Consumer demand in each region is specified as in model 3: $Q^D = Bp^{-\eta}$. The model is closed through the balance of trade condition where the sum of quantity demanded in each region is equal to the sum of quantity supplied by each region plus existing stocks. Different crop prices across regions are allowed in the model through the presence of transport costs and the existence of tariffs.

Social welfare impacts are obtained in each region as $\Delta SW = \Delta CS + \Delta PS + \Pi^M = \int_{p_1}^{p_0} Bp^{-\eta}dp + \int_{\bar{\pi}_0}^{\bar{\pi}_1} L(\bar{\pi})d\bar{\pi} + \theta L\nu wm$. With respect to the general social welfare function presented in section 2, equation (1), in this model the sum of ΔPS and Π^M represents changes in Π, and ΔCS represents changes in CW.

Moschini et al. (2000) use this approach to investigate social welfare impacts in 1999 of RR Soybean adoption in the U.S., South America and the rest of the world. The authors find for benchmark values a positive impact on social welfare of $ 1,157 million for the U.S., $223 million for South America, and $791 million for the rest of the world. The total world social welfare impact of $2,172 million is distributed as follows: 40% to consumers, 22% to producers and 38% to technology sellers.

For each region considered calibration of the Moschini et al. (2000) model requires data on market price and quantities for the specific crop, biotechnology adoption rate, average profit increase (or cost reduction) per acre due to biotechnology, average yield improvement per acre due to biotechnology, technology seller price markup, the elasticity of land supply, the consumer demand elasticity and available stocks of the specific crop.

These data requirements for the implementation of the indirect profit function make this model less empirically tractable than the models from Alston et al. (1995). Falck-Zepeda et al. (2000) propose an alternative approach that retains the empirical tractability of Alston et al. (1995) but includes profits of technology sellers in the social welfare function.

Model 5: Falck-Zepeda et al. (2000)

Large open economy model with technology spillovers and IPR rents.

Falck-Zepeda et al. (2000) model follows four steps. First, following Alston et al. (1995) the supply shift due to biotechnology is estimated. Second, the impact of this supply shift on world and regional prices is estimated. Third, changes in consumer and producer surplus are estimated following the Alston et al. (1995) procedure. Fourth, monopoly profits accruing to technology sellers are estimated.

Social welfare impacts are based on the following system of demand and supply functions:

$$(6)\quad \begin{cases} Q_A^S = \alpha_A + \beta_A(P + k_A) \\ Q_A^D = \gamma_A - \mu_A P \\ Q_{ROW}^S = \alpha_{ROW} + \beta_{ROW}(P + k_{ROW}) \\ Q_{ROW}^D = \gamma_{ROW} - \mu_{ROW} P \end{cases}$$

The change in consumer surplus in region A is given by $\Delta C\mathrm{S}_{\mathrm{A}} = \mathrm{P}_0\mathrm{Q}_{\mathrm{A0}}^{\mathrm{D}} Z(1{+}0.5Z\eta_A)$ where $Z = -(P_1 - P_0)/P_0 = K_{World}\varepsilon_A / \left[\varepsilon_A{+}\mathrm{s}_{\mathrm{A}}\eta_A{+}(1\text{-}\ \mathrm{s}_{\mathrm{A}})\eta_{ROW}^E\right]$. K_{World} is the vertical shift of the supply function for the world expressed as a proportion of the initial price, $K_{World} = \left(k_A + k_{ROW}\right)/P_0$, and can be computed for each region as in the closed economy model; and $P_0 = P_1 / \left\{1\text{-}\ \varepsilon_A K_{World} / \left[\varepsilon_A + s_A\eta_A + (1\text{-}\ s_A)\eta_{ROW}^E\right]\right\}$ and P_0 is the observed world price. The change in consumer surplus in the rest of the world is given by $\Delta C\mathrm{S}_{\mathrm{ROW}} = \mathrm{P}_0\mathrm{Q}_{\mathrm{ROW0}}^{\mathrm{D}} Z(1{+}0.5Z\eta_{ROW})$. The change in producer surplus in region A is given by $\Delta P\mathrm{S}_{\mathrm{A}} = \mathrm{P}_0\mathrm{Q}_{\mathrm{A0}}^{\mathrm{S}}(K_A - Z)(1{+}0.5\mathrm{Z}\varepsilon_A)$. The change in producer surplus in the rest of the world is given by $\Delta P\mathrm{S}_{\mathrm{ROW}} = \text{-}\mathrm{P}_0\mathrm{Q}_{\mathrm{ROW0}}^{\mathrm{S}}(K_{ROW} - Z)(1{+}0.5\mathrm{Z}\varepsilon_{ROW})$. The impact on social welfare in each region is given by the sum of changes of consumer and producer surplus in that region. Intellectual Property Right (IPR) rents for technology sellers are computed as $\mathrm{Q}_{\mathrm{GM}}(P_{GM} - c)$, where Q_{GM} is the quantity sold of genetically engineered seeds, P_{GM} is the price of genetically engineered seeds and c is the marginal cost of producing genetically engineered seeds.

For each region considered, calibration of this model requires data on market price and quantities for the specific crop, biotechnology adoption rate, average cost reduction per unit of land due to biotechnology, average yield improvement per unit of land due to biotechnology, technology sellers price markup, the supply elasticity, the export demand elasticity, and the demand elasticity.

Empirical applications are offered for developed countries by Falck-Zepeda et al. (2000) and Price et al. (2003). Falck-Zepeda et al. (2000a; 2000b) investigate social welfare impacts of RR soybeans and Bt cotton in the U.S. and the rest of the world in 1997. In the case of RR soybeans, the authors find a positive impact on social welfare of $963 million for the U.S. and $99 million for the rest of the world. The total world social welfare impact of $1,062 million is distributed as follows: 11% to consumers, 79% to producers and 10% to technology sellers. In the case of Bt cotton, the authors find a positive impact on social welfare of $179 million for the U.S. and $11 million for the rest of the world. The total world social welfare impact of $190 million is distributed as follows: 20% to consumers, 36% to producers and 45% to technology sellers.

Price et al. (2003) investigate social welfare impacts of RR soybeans, Bt cotton and HT cotton in the U.S. and the rest of the world in 1997. In the case of RR soybeans, the authors find a positive impact on social welfare of $288 million for the U.S. and $20 million for the rest of the world. The global social welfare impact of $308 million is distributed as follows: 23% to consumers, 9% to producers and 78% to technology sellers. In the case of Bt cotton, the authors find a positive impact on social welfare of $166 million for the U.S. and $46 million for the rest of the world. The global social welfare impact of $212 million is distributed as follows: $211 million to consumers, -$73 million to producers and $75 million to technology sellers. In the case of Ht cotton, the authors find a positive impact on social welfare of $156 million for the U.S. and $76 million for the rest of the world. The total world social welfare impact of $232 million is distributed as follows: $941 million to consumers, -$724 million to producers and $14 million to technology sellers. The negative impact on producer welfare is due to the negative impact biotechnology yield improvements have on market price, the model forecasts a decrease in world price equal to 0.17 % for RR soybeans, 0.69% for Bt cotton and 3.4% for Ht cotton.[12]

Empirical applications are offered for developing countries by Qaim and Traxler (2002) Traxler et al. (2003) and Traxler and Godoy-Avila (2004). Qaim and Traxler (2002) investigate social welfare impacts in Argentina as well as in the rest of the world in 2001. The authors find positive global social welfare impacts of at least $1.2 billion. Of this amount, 53% accrues to consumers, 13%

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[12] Results for Bt cotton are based on ARMS data.

to farmers and 34% to technology sellers. Traxler et al. (2003) and Traxler and Godoy-Avila (2004) investigate ex-post social welfare impacts of Bt cotton in Mexico from 1996 to 2000. The authors find a positive impact on social welfare of \$2.7 million annually, 0% of which accruing to consumers, 85% to farmers and 15% to technology sellers. In particular, seed companies in Argentina gained revenues for about \$30 million in 2001.

Oehmke and Crawford (2002) note that the approach used by Alston et al. (1995) and Falck-Zepeda et al. (2000) to calculate the K-shift in the supply function is very sensitive to the value chosen for the supply elasticity and suggest that greater efforts should be made to obtain more direct estimates of this shift factor. Qaim (2003) takes upon this suggestion and develops an alternative approach to computing shifts in the supply function.

Model 6: Qaim (2003)

Small open economy model (without technology spillovers but including IPR rents).

Qaim (2003) adopts the same approach used by Falck-Zepeda, Traxler and Nelson (2000) to estimate social welfare impacts but computes the K-shift factor as $K_t = \theta_t \Delta C^* / C^*$ where $\Delta C^* / C^* = -\left(C_1 / Q_1 - C_0 / Q_0\right) / (C_0 / Q_0)$ is the percent per unit cost reduction due to biotechnology. Furthermore the open economy is assumed to be small, facing a perfectly elastic demand function. Empirical application of this approach are offered by Pray et al. (2001), Qaim (2003) and Demont and Tollens (2004).

Pray et al. (2001) analyze *ex post* social welfare impacts of Bt cotton in China in 1999. The authors find a positive impact on social welfare of at least \$53 million distributed as follows: 86% to farmers and 14% to technology sellers. There is no impact on consumer surplus because the Chinese government administers a minimum support price for cotton and at this minimum price level the demand is perfectly elastic.[13]

Qaim (2003) carries out an *ex post* and *ex ante* social welfare impact analysis for Bt cotton in India in the time period 2002-2005. The author estimates an average annual positive impact on social

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[13] These figure are averages, with respect to CAAS and MDP Bt cotton varieties, weighted by the number of acres planted to each variety (see Table 7 in Pray, Huang and Qiao, 2001).

welfare equal to $122, 67% of which going to producers and 33% to technology sellers. There is no impact on consumer surplus because the Indian government administers a minimum support price for cotton and at this minimum price level the demand is perfectly elastic.

Demont and Tollens (2004) investigate *ex post* social welfare impact of Bt maize in Spain in the period 1998-2003. The authors find an average social welfare impact equal to 1.2 million Euro or $ 1.49 million, 64.5% going to producers and 35.5% to technology sellers. There is no impact on consumer surplus because Spain is assumed to be a small open economy facing a perfectly elastic demand for maize.

None of the models presented so far takes into consideration, in their empirical application, the uncertainty and irreversibility associated with the adoption of a new technology, which is important for an *ex ante* technology assessment. These factors are instead included in model 7, the real option approach for biotechnology innovations, suggested by Wesseler and Weichert (1999), Morel et al., (2003), and Wesseler (2003).

Model7: The real-option approach (Wesseler and Weichert, 1999)

Wesseler and Weichert (1999) and others (Morel et al., 2003) have pointed out that ex-ante assessments of new transgenic crops needs to consider the uncertainty about the future benefits and costs of the technology as well as the irreversibility of future benefits and costs. Demont et al. (2004) suggest to group benefits and costs according to whether or not they are irreversible and whether or not they are private or public (Figure 2).

With respect to biotechnology, examples of irreversible costs are potential biodiversity losses and development of resistance due to transgenic crops. Irreversible benefits are gains in human health and biodiversity due to reduced pesticide use. In this context the option of postponing or anticipating the adoption of the new technology becomes of value to society and should be taken into consideration when investigating welfare impacts of new technologies such as biotechnology. Studies aiming at taking this social welfare component into consideration follow a real-option approach. The real-option approach has been proposed and used by Wesseler and Weichert (1999), Morel et al. (2003), Wesseler (2003), and Demont et al. (2004).

In the real option approach, the decision rule to adopt biotechnology is modeled generally as follows:

$$W^* = \frac{\beta}{\beta - 1}(I - R) \text{ or } I^* = R + \frac{W}{[\beta/\beta - 1]}, \; I > R \tag{4}$$

with β being the positive root of a Fokker-Planck equation as part of solution finding the option value, where W follows a geometric Brownian motion (a non-stationary stochastic process) and represents the amount of incremental social reversible net-benefits of the biotechnology product. I represents the incremental social irreversible costs and R the incremental social irreversible benefits. $\{\beta/(\beta - 1)\}$ is the so-called hurdle rate and being greater than one. The hurdle rate indicates to what measure incremental social reversible benefits W need to be higher than net incremental irreversible costs ($I - R$) to justify an immediate release. W^* is the resulting threshold value that the actual incremental reversible benefits, W, have to meet. Wesseler (2003) has argued that it is easier to identify the incremental social reversible net-benefits and the incremental social irreversible benefits than the amount of incremental social irreversible costs and proposes to identify I^* the maximum incremental, social tolerable, irreversible costs (MISTICS)[14].

It is important to note that for the calculation of the incremental social reversible benefits partial equilibrium models as discussed before are used. Therefore the approach faces the same limitations. We believe, nevertheless, that for *ex-ante* assessment considering uncertainty and irreversibility is an important innovation.

An empirical application of the approach is offered by Demont, Wesseler and Tollens (2004). They carry out an ex-ante analysis of social welfare impacts of HT sugar beet. The authors find that biotechnology would yield social reversible benefits in the order of \$140 million in the EU's sugar sector. Social net irreversible costs associated to biotechnology should be lower than reversible benefits by a factor equal to 1.67, i.e. the hurdle rate, to justify adoption. [15]

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[14] A more extensive discussion on the MISTICS is provided in Scatasta et al. (forthcoming).

[15] The authors show that this amount corresponds to less than \$1 per household.

4. Critical Assessment of the Social Welfare Impact Studies

The evidence presented so far seems to suggest that the adoption of genetically engineered crops had or has the potential to yield sizeable gains in social welfare. The only exception being farmer welfare impact estimates for Bt corn in the U.S. from Carpenter and Gianessi (2001). At a first glance, the great variety of models used by researchers seems to confer robustness to the former finding. Yet a closer look at common assumptions and presumptions underlying those models reveals basic limitations that could challenge the reliability of this evidence for policy purposes.

Price et al. (2003) highlight similarities among models proposed by Falck-Zepeda et al. (2000) and Moschini et al. (2000) by calibrating their model (based on Falck-Zepeda et al., 2000) with the same values used by Moschini et al. for the supply elasticity (0.8), herbicide cost savings per hectare ($20), yield advantages (0), soybean demand elasticity (-0.4), seed costs per hectare ($45 for the U.S. and $40 for ROW), seed costs for ht soybeans (43% higher than conventional seeds in the U.S. and 22% higher than conventional in the ROW). Table 3 shows that recalibration reconciles most differences, with the exception of the negative impact on ROW producer surplus, which is significantly higher in Price et al. (2003) (-$112.1) than in Moschini et al. (2000) (-$31).

Thus, results of social welfare impact studies seem to be more sensitive to changes in underlying assumptions about demand and supply elasticities and measurements and aggregation of yield and production cost effects, than the modeling approach. This can be explained by the presence of common features such as: the use of Marshallian surpluses to represent changes in welfare, the exclusion from the analysis of long-term environmental impacts, of environmental impacts other than those related to insecticide and herbicide use, of issues related to consumer acceptance of transgenic food products, and of transaction costs.

In all of the above models, furthermore, researchers assume that marginal costs of producing genetically engineered seed are the same of those for conventional seeds and any increase in price of genetically engineered seeds above the price of conventional seeds (for example technology fees) contributes to monopoly profits (or rents) from IPR’s. This assumption may overestimate (underestimate) monopoly profits if marginal costs of production are higher (lower) for genetically engineered seed than for conventional seeds.

For the lack of space we focus on those methodological issues that are likely to have a significant impact on the size and distribution of social welfare impacts of transgenic crops. In paragraph 4.1 we discuss values chosen for demand and supply elasticity. In paragraph 4.2. we present a brief overview of farm level impact studies and highlight methodological issues arising in the measurement of yield improvements and cost reduction. In paragraph 4.3. we discuss data sources and possible sample biases. In paragraph 4.4 we present an overview of the literature dealing with long-term environmental impacts of transgenic crops such as the development of resistance.

4.1 The Choice of Demand and Supply Elasticity

The potential impact of different choices for the value of demand and supply elasticities on social welfare impact estimates is investigated in Qaim (1999), Falck-Zepeda et al. (2000), Moschini et al. (2000) and Price et al. (2003). Qaim (1999) performs a sensitivity analysis using supply elasticity values in the interval [0-2]. Falck-Zepeda et al. (2000) construct a triangular distribution around two alternative estimates given in the literature for the supply elasticity. Moschini et al. (2000) and Price et al. (2003) carry out the sensitivity analysis with respect to half and double of the benchmark values chosen for demand and supply elasticities. The direction of overall global social welfare impact estimates does not change, but the size of this estimate does change considerably in some cases.

For example, in the case of RR soybeans, Price et al. (2003) allow demand elasticity to vary between -0.25 and -1.00 and the supply elasticity between 0.14 and 0.56. The authors find a 100 percent increase in global welfare impacts for lower elasticity values and a 43 percent decrease for higher elasticity values (see table 4). The distribution of benefits among stakeholders also changes dramatically; the gain for U.S. farmers becomes five times higher for lower elasticity values, and it becomes a loss for higher elasticity values.[16]

Taking these findings into consideration, we note that the following values have been used in the literature to represent soybean demand elasticity in the U.S. (see also Table 3): infinite, -0.5, -0.42, and -0.4. For the U.S. soybean supply elasticity the following benchmark values have been used: 0, 0.22, 0.28 and 0.8. In our opinion this range of variation in benchmark values (especially for the supply elasticity) makes social welfare impact estimates difficult to compare and their reliability

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[16] Similar conclusions can be reached for Bt cotton looking at table 4. A similar analysis for Bt corn is lacking.

difficult to judge. Finally we note that studies applying the change in revenue method to RR soybeans in the U.S., such as Carpenter and Gianessi (2001), by not applying any theoretically consistent aggregation method, implicitly presume highly inelastic supply functions (supply elasticity equal to 0) and highly elastic demand functions (demand elasticity is infinite). This presumption seems not consistent with values used in other studies and therefore aggregation methods based on simple homothetic extrapolation should be interpreted with due care. [17]

4.2 Measurement Issues: Yield Improvements and Cost Reductions at the Farm Level

Social welfare impacts estimates are based on farm level net benefits of transgenic crops. Analogous to the case of pesticides, many authors have studied farm level net benefits of GM crops in terms of changes in yields and weed/pest control management practices in a production function framework. Examples of farm level impact studies are offered by Benbrook (1999, 2003), Brookes (2003a,b), Carpenter and Gianessi (2001), Carpenter et al. (2002), Fernandez-Cornejo and McBride (2002), Fulton and Keyowski (1999), Huang et al. (2003), Ismaël et al. (2003), Klotz-Ingram et al. (1999), McBride and Books (2000), Pray et al. (2001, 2002), Qaim (1999), Qaim and de Janvry, (2003), Qaim and Zilberman (2003), SERECON and KOCH (2001), Thirtle et al.(2003), Traxler et al. (2003) and Traxler and Godoy-Avila (2004).[18]

The evidence presented by these studies about impacts of GM crops on yields, pesticide/herbicide use and gross margins is mixed. Brookes (2003a,b), Huang et al. (2003), Qaim and de Janvry (2003), Qaim and Zilberman (2003), Pray et al. (2002), SERECON and KOCH (2001), Roberts et al. (1999), find the impact of GM crops on yields to be positive. McBride and Books (2002) find GM crops to have no impacts on yields. Recent research on North Carolina's farmers did not reveal any statistically significant yield differences at the 95% level between HT maize, cotton and soybeans and their conventional counterparts (Marra et al., 2004, p. 43). Likewise, European field trials showed no increase in any HT crop (Schütte, 2003). It is certain, however, that the impact of GM crops on yields varies over time (Ismaël et al., 2003) and among crops (Carpenter and Gianessi, 2001; Klotz-Ingram et al., 1999).

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[17] As noted previously, only in this case changes in revenues can approximate changes in producer surplus.

[18] Previous studies investigating farm level impacts of GM crops are reviewed in Marra et al. (2002).

Huang et al. (2003), Qaim and De Janvry, (2003), Qaim and Zilberman (2003), Fernandez-Cornejo and McBride (2002), McBride and Books (2000), Benbrook (1999) and Roberts et al. (1999) find that adoption of GM crops reduces insecticide and herbicide use. SERECON and KOCH (2001) report that adoption of HT oilseed rape increases herbicide use. The impact of GM crops on insecticide/herbicide use seems to vary across crops (Carpenter and Gianessi, 2001), regions (Klotz-Ingram et al., 1999) and time (Benbrook, 2003).

The impact of GM crops on gross margins is found to be positive in Brookes (2003), Pray et al. (2002), SERECON and KOCH (2001), Klotz-Ingram et al. (1999), Reddy and Whiting (1999), Roberts et al. (1999), Arnold et al. (1998). McBride and Books (2000), Couvillon et al. (2000), Benbrook (1999), Fernandez-Cornejo et al. (1999), Ferrell et al. (1999) and Graeber et al. (1999). Fernandez-Cornejo and Klotz-Ingram (1998) find instead that GM crops have no significant impact on gross margins. Brookes (2003a), Carpenter and Gianessi (2001), Hyde et al. (1999; 2000), Lauer and Wedberg (1999), Rice and Pilcher (1998), show that the impact of GM crops on gross margins varies across regions. In particular, the impact of Bt corn on gross margins is tied to infestation levels and gains may disappear in those areas where infestation levels are low. Ismaël et al. (2003) and Qaim and De Janvry (2003) show that the impact of GM crops on gross margins varies over time. Fernandez-Cornejo and McBride (2002) show that the impact of GM crops varies across crops. Carpenter and Gianessi (2002), show that the impact of GM crops on gross margins varies across crops and over time.

Methodologies used to measure impacts of GM crops on yields, herbicide use and insecticide use contribute to the differences in these findings. With respect to measures of impacts on yields, the source of data may induce biases in the estimation. There are three possible sources: official data (Benbrook, 2003; Fernandez-Cornejo and McBride, 2002; Carpenter and Gianessi, 2001; McBride and Books, 2000; Klotz-Ingram et al. 1999), ad-hoc farmers' surveys (Brookes, 2003a,b; Huang et al., 2003; Ismael et al., 2003; Qaim and De Janvry, 2003; Pray et al., 2002; SERECON and KOCH, 2001), and field trials (Qaim and Zilbermann, 2003; Benbrook, 1999; Gianessi and Carpenter, 1999; Reddy and Whiting, 1999; Roberts et al., 1999; Arnold et al., 1998; Rice and Pilcher, 1998).

Marra et al. (2003) analyze advantages and disadvantages of each type of data source. Field trials comparing yields and/or input use of transgenic varieties relative to their conventional isogenic[19] parent will measure yield gains due to the transgene but will overestimate the benefits of transgenic crops if the conventional isogenic parent is not among those varieties the farmer has chosen to grow in the area. Side-by-side variety trials may underestimate the benefits of transgenic crops due to the halo effect, i.e., pest reduction benefits due to the transgenic crop may spill over to the conventional trial. The yield-maximizing pest control regimes used by scientists in trials may differ from profit-maximizing pest control regimes used by farmers. Biases in the results are present any time decisions made by scientists differ from those made by farmers (see Alston, Norton and Pardey, 1995). Even when all decisions are taken by farmers, biases are still possible in the way farmers assign fields to one technology or the other.

In the case of sugar beet breeding e.g., the incorporation of traits into accepted cultivars can be a time-intensive process because of the biennial nature of sugar beet. The time involved is amplified when dealing with transgenic traits. In the time it takes breeders to produce a transgenic cultivar that is commercially acceptable, newer, higher-yielding conventional cultivars will have entered the market. If this is the case, economic analyses should include side-by-side comparisons of locally adapted, top-yielding cultivars regardless of whether a HT version of the cultivar is available (Kniss et al., 2004).

Official and ad-hoc farmer surveys also have disadvantages. Official farmer surveys conducted by the USDA (1999) do not allow for within farm comparisons. The latter would allow eliminating systematic differences between adopters and non-adopters. Yet these surveys have a large sample size and constitute the only long-term source of data. *Ad hoc* farmer surveys conducted by researchers allow for within farm comparisons, but even the results of this comparison may be biased downwards due to profit maximizing choices made by farmers in the allocation of their land to one technology or the other, i.e., comparison may be in the end carried out among crops that are not substituted for one another. Marra et al. (2003) show that benefits of GM crops vary depending on the way the comparison between transgenic and conventional varieties is carried out, namely, if

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[19] Isogenic varieties have exactly the same genetic composition with the exception of the inserted gene.

comparison is carried out between transgenic and conventional acres within the same farm, of adopters relative to non-adopters, or with respect to the total number of acres in the analyzed area.

With respect to measures of impact on herbicide use, Benbrook (2003), for example, finds that GM crops reduce herbicide use in the short run, but increase it in the long run. Gianessi et al. (2002) criticize Benbrook's results because the author compares herbicide use rates of GM crops to national average rates. Gianessi et al. (2002) state that it would be more reasonable to follow Carpenter and Gianessi (2001) and identify herbicide use rates above national averages as stemming from those farmers who have superior weed problems and are more likely to adopt GM crops. Another problem of pesticide/herbicide use studies relates to the fact that pesticide/herbicide use is generally measured adding up volumes of active ingredients. Nelson and Bullock (2003) believe that toxicity and composition of active ingredients are better indicators of herbicide use than volume of active ingredient from an environmental point of view. The authors propose the use of a well-known acute mammalian toxicity measure, the LD_{50} dose for rats. Using 1995 data collected for soybeans by Pike et al. (1997), the authors show that glyphosate-resistant soybeans are more environmentally friendly than conventional soybeans (see table 6).

Uncertainty about accuracy of data and measurement methods is taken into consideration in Demont and Tollens (2004) in a stochastic sensitivity analysis. Instead of assuming deterministic values as generally done in sensitivity analysis the authors consider triangular distributions of uncertain parameters and a lognormal distribution for insect damage variability to analyze the impact of Bt maize in Spain from 1998 to 2003.

4.3 Aggregating Issues: Sample Bias.

Data to perform this type of analysis can be obtained through official statistics, ad-hoc farmer surveys, field trials and expert opinions. For the U.S., official statistics are available in the ARMS (Agricultural Resource Management Study) database maintained by the USDA and in the EMD II (Enhanced Market Data II). *Ad hoc* farmers surveys, field trials and expert opinions are usually gathered for the purposes of the specific study at hand. ARMS and EMD II data are used in social welfare impact studies from Carpenter and Gianessi (2001), Falck-Zepeda et al. (2000) and Price et al. (2003).

Moschini et al. (2000) use survey data from Iowa State to represent U.S. cost budgets for RR soybeans. Brookes (2003a,b) uses ad-hoc farmer surveys and Demont and Tollens (2004) construct a bio-economic model calibrated on field trials carried out in Spain during 1995-1998. Ad-hoc farmer surveys are also used to investigate welfare impacts of Bt cotton in China by Pray et al. (2001) and the same dataset is then used by Huang et al. (2003) and Pray et al. (2002). The same type of surveys are used by Ismael et al. (2003) and Thirtle et al. (2003) to investigate welfare impacts of Bt cotton in South Africa.

In order for farm level impacts to be extended to farmers in a wider region or country, the sampling procedure used for the survey has to be random and if sampled farmers do not represent basic demographic characteristics of the population of farmers targeted by the study, appropriate weighting should be applied. When reporting on *ad hoc* farmer surveys, it is our opinion that the following information should be given in the study: population definition, basic demographics and size, sample basic demographics and size, sampling procedure (random, stratified, cluster), sampling error, and response rate. This means that farmer surveys should not be treated any differently than consumer surveys. In consumer surveys the reason for using a probability sample is to be able to account for different consumer preferences. In farmer surveys we want to be able to account for different managerial abilities. We could not find any *ad hoc* farmer survey reporting the required information as suggested above.

4.4 Long-term Environmental Impacts of Transgenic Crops.

Zadocks and Waibel (2000) note that, for the case of pesticides, analyzing farm level costs and benefits of a pest control management system in a production function framework may lead to significant overestimation of the benefits of such a system (see Lichtenberg and Zilberman, 1986, Babcock et al., 1992, Rola and Pingali, 1993, Chambers and Lichtenberg, 1994, Carpentier and Weaver, 1997, Saha et al., 1997, Waibel and Fleischer, 1998).

Farm level impact studies limit their analysis to one environmental impact of GM crops: insecticide/herbicide use (except for SERECON and KOCH, 2001). Carpenter et al. (2002) analyze potential environmental impacts of GM soybean, corn and cotton crops relative to their conventional counterparts and identify key aspects that should be taken into consideration when analyzing costs and benefits of GM crops such as changes in pesticide use patterns, impacts on soil erosion, moisture retention, soil nutrient content, water quality, fossil fuel use, and greenhouse gasses, whether the GM crop has acquired weediness traits, the extent to which GM crops hybridize with local plants and consequences for genetic diversity, the extent to which targeted pests and weeds develop resistance to plant-protection traits, impacts on weed and secondary insect pest populations that might affect the agricultural or ecological system, and impacts on non-target and beneficial organisms.

Farm level impacts studies, furthermore, limit their analysis to one (Brookes, 2003a,b; Huang et al., 2003; Quaim and Zilbermann, 2003; Mc Bride and Books, 2000; Benbrook, 1999; Klotz-Ingram et al., 1999; Roberts et al., 1999; Rice and Pilcher, 1998), two (Ismael et al., 2003; Qaim and De Janvry, 2003; Fernandez-Cornejo and McBride, 2002; Carpenter and Gianessi, 2001; Gianessi and Carpenter, 1999), four (SERECON and KOCH, 2001) or five years of data (Pray et al., 2002). Benbrook (2003), in a study analyzing eight years of data, shows that U.S. herbicide use declined in the first five years of GM crop adoption, but it went back up again in the successive three years. The author explains that this trend might be due to changes in weed communities and development of resistance caused by heavy reliance on HT crops. The problem of resistance is well known in the scientific community, Kennedy and Whalon predicted in 1995 that benefits of GM crops could disappear after the first few years depending on the speed of development of resistant plants and insects. Thus, the use of time series data longer than five years is necessary to be able to draw conclusions about the long-term farm level impacts of GM crops.

5. Conclusion

This paper aims at contributing to the ongoing discussion about social welfare impacts of genetically engineered crops focusing on methodological issues arising from existing literature. We analyzed the work of several authors and identified seven basic models used in the literature to estimate social welfare impacts of genetically engineered crops.

The evidence presented in this study seems to suggest, with a few exceptions, that the adoption of genetically engineered crops had or has the potential to yield sizeable gains in social welfare. At a first glance, the great variety of models used by researchers seems to confer robustness to their findings. Yet a closer look at common assumptions and presumptions underlying those models, such as the use of Marshallian surpluses to represent changes in welfare and the exclusion from the analysis of long-term environmental impacts, of environmental impacts other than those related to insecticide and herbicide use, of issues related to consumer acceptance of transgenic food products, and of transaction costs, reveals basic shortcomings that could challenge the reliability of this evidence for policy purposes.

Results of social welfare impact studies, furthermore, seem to be very sensitive to changes in underlying assumptions about demand and supply elasticities, measurements and aggregation methods used to quantify impacts on yields and production costs,. Studies based on ad hoc farmer surveys often lack basic information about sampling procedure and characteristics of the population of farmers targeted by the study making it difficult to extrapolate results to a wider region and/or population than that sampled by the authors.

Several studies have conducted an *ex ante* assessment of social welfare impacts of transgenic crops without considering uncertainty and irreversibility. This can be solved by using a real option approach. Still, even within the real option approach incremental social benefits are calculated using the models discussed above.

We conclude by observing an additional and important knowledge gap. All of the studies analyzed in this review assume, more or less, that new technologies can reach farmers at no cost. While this might be correct for industrial countries where technology distribution markets exist, for developing countries this is definitely not the case. The fact that these costs are not taken into consideration should be kept in mind when interpreting the results of social welfare impacts studies carried out for developing countries.

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Table 1: Summary of models and model characteristics presented in section 3

Model number	**Producer Welfare**		**Consumer Welfare**	**Other Welfare components**	**Economy**			**Uncertainty and/or Irreversibility**	**N. of Studies**
	Farmers	**Technology sellers**			**Closed**	**Small Open**	**Large Open**		
0	x				x				4
1	x		x		x				2
2	x		x	x		x	x		2
3	x	x	x		x				1
4	x	x	x				x		1
5	x	x	x				x		4
6	x	x	x			x			3
7	x	x	x	x			x	x	1

Table 2: Summary of annual social welfare impacts in million U.S. dollars[20]

Reference	**Year**	**Region**	**Producer welfare**		**Consumer Welfare**	**Total Social Welfare (million U.S. Dollars per year)**	**Social Welfare per adopted hectare (U.S.Dollars per hectare)**	**Million adopted hectares (yearly averages) [adoption rate %]**
			Farmers	**Technology sellers**				
Bt Corn								
Brookes (2003a)	2002 Farmer surveys (12 interviews)	Spain	26.76			26.76	154.93	0.173 (0.0225) [36 (4.5)]
Demont and Tollens (2004)	1998-2003 Brookes data and NCFAP data	Spain	1.18	0.59		1.78	46.36	0.03 [5.7]
Ostlie et al. (1997)	1997	U.S.	43.92			43.92	17.80	2.47 [7.60]
Benbrook (2001)	1996-2001 Doane Marketing Data	U.S.	-18.40	131.60		113.20	-3.24	5.20 [16.20]
Carpenter and Gianessi (2001)	1998-1999 USDA NASS data and NCFAP data	U.S.	-6.10			-43.50	-6.10	7.13 [22.34]
Trigo and Cap (2003)	1998-2003 Farmer Survey (299 interviews)	Argentina	14.07	52.56		66.63		
Scatasta Wesseler and Demont (2005)	Ex-ante New Cronos EU-Spell, Field Trials	European Union				40.21	109.87	[30] (ceiling)
Ht Corn								
Scatasta Wesseler and Demont (2005)	Ex-ante New Cronos EU-Spell Field Trials	European Union				69.24	113	[40] (ceiling)

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[20] ROW = Rest of the world.

Table 2: continue ....

			Producer welfare					
Reference	**Year**	**Region**	**Farmers**	**Technology sellers**	**Consumer Welfare**	**Total Social Welfare (million U.S. Dollars per year)**	**Social Welfare per adopted hectare (U.S.Dollars per hectare)**	**Million adopted hectares (yearly averages) [adoption rate %]**
Bt Cotton								
Falck-Zepeda, Traxler and Nelson (1999, 2000a, 2000b) and Traxler and Falck-Zepeda (1999)	1996-1998 Plexus Marketing Research Inc. Timber Mill Research Inc. Data	U.S. ROW World	105 -15	80.00	45	215.00	250.54	0.86 [15.70]
Price et al. (2003)	1997 ARMS data	U.S. ROW World	61.40 -134.80 -73.40	74.90	29.90 181.20 211.10	166.20 46.40 212.60	197.80	0.84 [15.33]
Price et al. (2003)	1997 Enhanced Market Data II	U.S. ROW World	117.40 -234.40 117.00	74.90	50.40 291.50 341.90	242.70 57.1 299.80	288.93	0.84 [15.33]
Carpenter and Gianessi (2001)	1999 USDA NASS data and NCFAP data	U.S.	99.00			99.00	74.02	1.34 [23.99]
Pray, Huang and Qiao (2001) and Huang et al. (2003)	1999 Farmer Survey (283 interviews)	China	69.64	30.94		100.58	264.69	0.38 [17.55]
Pray et al. (2002) and Huang et al. (2002)	1999-2001 Farmer Survey (1049 interviews)	China	633.11			633.11	469.67	1.35 [30.95]
Traxler et al. (2003), Traxler and Godoy-Avila (2004)	1996-2000 Sereasa Data (638 producers)	Mexico	2.30	0.41		2.7	347.06	0.01 [33.00]
Ismael et al. (2003) Thirtle et al. (2003) Bennet et al (2003)	1999-2000 Farmer Survey (100 interviews)	Makhathini Flats, South Africa	62.50			62.50	25.00	2.5 [8.25]

Table 2: continue ....

Reference	**Year**	**Region**	**Producer welfare**		**Consumer Welfare**	**Total Social Welfare (million U.S. Dollars per year)**	**Social Welfare per adopted hectare (U.S.Dollars per hectare)**	**Million adopted hectares (yearly averages) [adoption rate %]**
Bt Cotton								
Bennet et al (2004)	2002-2003 Farmer Survey (3496 interviews)	India	23.3			23.3	358.5	0.1 [0.81]
Qaim (2003)	2002-2003 projections 2001 Field trials (400 Farmers)	India	16.6	51.4		68.1	420.5	0.2 [2.03]
Qaim and De Janvry (2003)	1999-2002 Farmer Survey (299 interviews)	Argentina	0.3	1.7		2.0	118.1	0.02 [0.04]
Qaim Cap and De Janvry (2003)	1999-2002 Farmer Survey (299 interviews)	Argentina				1.6	91.3	0.02 [0.04]
Trigo and Cap (2003)	1998-2003 Farmer Survey (299 interviews)	Argentina	1.2	5.8		7.0	573.1	0.01 [0.04]
Ht Cotton								
Price et al. (2003)	1997 ARMS data	U.S.	9.6	14.4	132.2	156.20	189.79	0.8 [15.33]
		ROW	-733.3		808.8	75.5		
		World	-723.7		941.0	231.7		
RR Soybeans								
Brookes (2003b)	2003 Farmer Survey (? Interv.)	Romania	7.1			7.17	223.1	0.03 [48.00]
Carpenter and Gianessi (2001)	1999 USDA NASS data and NCFAP data	U.S.	235.0			235.0	13.8	17.0 [57.00]
Moschini, Lapan and Sobolevsky (2000)	1999	U.S.	156	358.00	81	596	35.06	17 [57.00]
		South America	27		36	64		
		ROW	-58		201	144		
		World	125		318	804		

Table 2: continue ....

Reference	Year	Region	Producer welfare		Consumer Welfare	Total Social Welfare (million U.S. Dollars per year)	Social Welfare per adopted hectare (U.S.Dollars per hectare)	Million adopted hectares (yearly averages) [adoption rate %]
RR Soybeans								
Falck-Zepeda, Traxler and Nelson (2000b)	1997 Plexus Marketing Research Inc. Timber Mill Research Inc. Data	U.S.	467.5	109.9	60.3	637.7	130.8	4.9
		ROW	19.2		92.6	111.7		[17.0]
		World	486.7		152.8	749.4		
Price et al. (2003)	1997 ARMS data	U.S. ROW World	61.5	210.0	16.3	287.8		
Trigo and Cap (2003)	1996-2001 Farmer Survey (299 interviews)	Argentina	746.6	861.4		1607.9		
Ht Sugar Beet								
Demont Wesseler and Tollens (2004)	Ex-ante EU-Spell	European Union				161.1	189.4	
Virus Resistant Potatoes								
Qaim (1999)	Ex-ante	Mexico	6.0		1.2	7.2		
Mixed Major Crops								
Frisvold et al. (2003)	Ex-ante	World	-347.0		954.0	590.0		

Table 3: Model comparison – social welfare impacts of RR *soybeans in the U.S. and ROW in 1997*

Stakeholder	Surplus gain Price et al. (2003) Original		Surplus gain Price et al. (2003) Recalibrated		Surplus gain Moschini et al. (2000) Original	
	$ million	% of total	$ million	% of total	$ million	% of total
U.S. Producers	61.5	20	135.2	19	156.0	19
U.S. Consumers	16.3	5	93.0	13	81.0	10
Technology sellers	210.0	68	368.8	51	358.0	45
ROW Producers	-35.0		-112.1		-31.0	
ROW Consumers	54.8		227.7		237.0	
Net ROW	19.8	6	115.7	16	206.0	26
World Benefit	307.6		702.7		804.0	

Source: Price et al. (2003)

Table 4: Sensitivity analysis – demand and supply elasticities.

Reference	Year	Region	Benchmark values		Sensitivity analysis		% Change in world social welfare impact estimates
			Demand elasticity	Supply elasticity	Demand elasticity	Supply elasticity	
Bt Corn							
Brookes (2003b)	1999-2001	Spain	infinite	0			
Carpenter and Gianessi (2001)	1998-1999	U.S.	infinite	0			
Demont and Tollens (2004)	1998-2003	Spain	infinite	2.5			
Bt Cotton							
Carpenter and Gianessi (2001)	1998-1999	U.S.	infinite	0			
Thirtle et al. (2003)	Ex-ante	South Africa	infinite	0			
Falck-Zepeda, Traxler and Nelson (2000)	1997	U.S.	-0.101	0.84			
Falck-Zepeda, Traxler and Nelson (2000)	1997	ROW	-0.13	0.15			
Price et al. (2003)	1997	U.S.	-0.5	0.47	-0.25, -1.00	0.235, 0.94	+74, -37
Price et al. (2003)	1997	ROW	-0.15	0.15	-0.075, -0.30	0.075, 0.30	+74, -37
Pray, Huang and Qiao (2001)	1999	China	infinite				
Traxler et al. (2003)	1996-2000	Mexico					
Traxler and Godoy-Avila (2004)							
Qaim (2003)	Ex-ante	India	infinite	0.43			
Ht Cotton							
Price et al. (2003)	1997	U.S.	-0.5	0.47	-0.25, -1.00	0.235, 0.94	small change
Price et al. (2003)	1997	ROW	-0.15	0.15	-0.075, -0.30	0.075, 0.30	small change

Table 4: continue…

Reference	Year	Region	Benchmark values		Sensitivity analysis		% Change in world social welfare impact estimates
			Demand elasticity	Supply elasticity	Demand elasticity	Supply elasticity	
RR Soybeans							
Brookes b	2003	Romania	infinite	0			
Carpenter and Gianessi (2001)	1998-1999	U.S.	infinite	0			
Moschini, Lapan and Sobolevsky (2000)	1999	U.S.	-0.4	0.8	-0.2, -0.8	0.4, 1.6	-0.3, 0.6
Moschini, Lapan and Sobolevsky (2000)	1999	South America	-0.4	1	-0.2, -0.9	0.4, 1.7	-0.3, 0.6
Moschini, Lapan and Sobolevsky (2000)	1999	ROW	-0.4	0.6	-0.2, -0.10	0.4, 1.8	-0.3, 0.8
Qaim and Traxler (2002)	2001	World					
Falck-Zepeda, Traxler and Nelson (2000)	1997	U.S.	-0.42	0.22		0.92	-59
Falck-Zepeda, Traxler and Nelson (2000)	1997	ROW	-0.07	0.3			-59
Price et al. (2003)	1997	U.S.	-0.5	0.28	-0.25, -1.00	0.14, 0.56	100, -42
Price et al. (2003)	1997	ROW	-0.25	0.3	-0.125, -0.5	0.15, 0.6	100, -43
Ht Sugar Beet							
Demont, Wesseler and Tollens (2004)	Ex-ante	European Union	infinite (fixed prices and quota)	0.02-0.6			
Virus Resistant Potatoes							
Qaim (1999)	Ex-ante	Mexico	-0.41	0.3, 0.4, 0.5		0 to 2	Higher supply elasticity values increase gains for large farmers
Mixed Major Crops							
Frisvold et al. (2003)	Ex-ante	World					

Table 5: Measurement issues – RR Soybeans impact on herbicide use in the U.S.

References	**Year**	**Measurement unit**	**Absolute impact**	**Percentage change**
Benbrook (2003)	1999	Million pounds active ingredient	+7.8	+10%
Fernandez-Cornejo and McBride (2002)	1999	Million acre-treatment*	-16	-5%
Carpenter and Gianessi (2001)	1999	Million acre-treatment*	-19	-12%
Nelson and Bullock (2003)	1997	Thousand LD50 toxicity doses for rats	-199	-40%

*Acre-treatment = number of active ingredients per acre x number of repeated applications

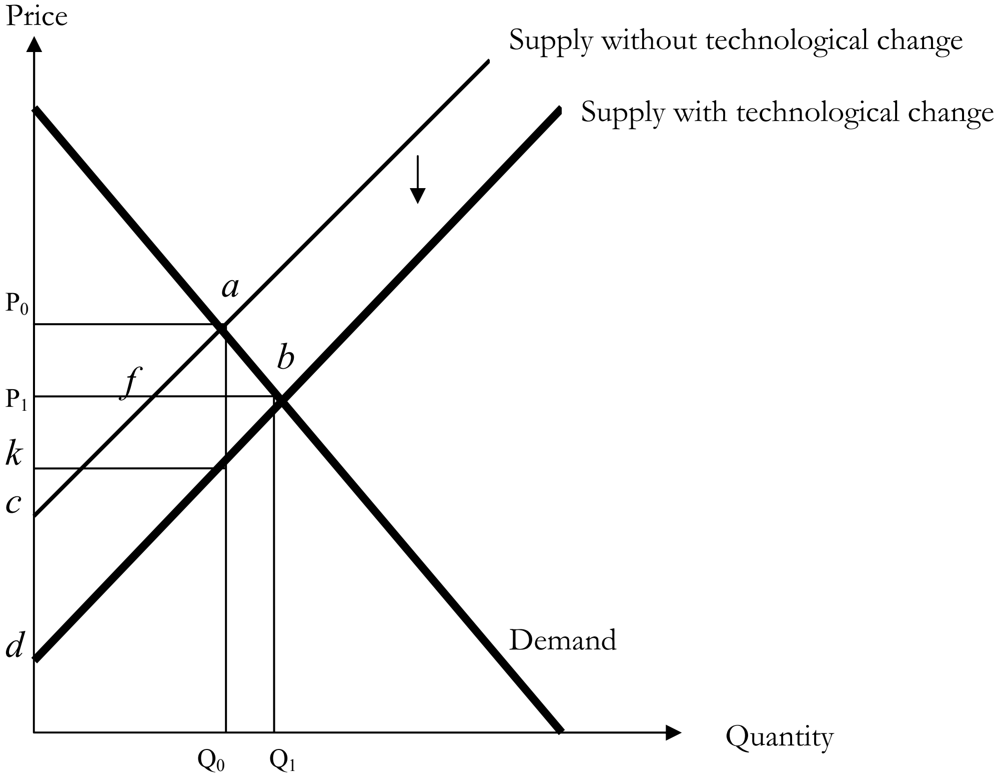

Figure 1. The economic surplus model or market equilibrium displacement model.

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

Figure 2. Dimensions of costs and benefits for ex-ante welfare analysis of transgenic crops