A Market Impact Analysis of Soybean Technology Adoption

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Abstract

This article analyzes the welfare benefits of the adoption of Roundup Ready (RR) technology by producers and consumers in the United States and the ROW. Based on a survey data and other secondary data sources we calculated economic surpluses that revealed that while producers and consumers in the U.S. gain some welfare benefits from the adoption, the economic surplus accrued by consumers is offset by producer losses. Our estimates also show that consumers in the rest of the world (ROW) gained economics surpluses while producers in the ROW lost economic surplus due to the non-adoption of RR soybean technology. The estimated total surplus for the pivotal supply shift ($4.64 million) was about half that of the parallel shift ($8.21 million).

Key words: market, surplus, pivotal, marshallian, estimates, welfare

Introduction

While there has been conflicting findings on the impact of the adoption of new agricultural technologies on profitability, it has been well-established in the literature that improvements in technology have the potential to increase productivity, raise real incomes and thus enhance economic growth. For example, Marra et al. (2002) reported findings of an increase in profitability from the use of Roundup Ready canola. Increased in net gains from Bt corn has also been reported Shoemaker et al. (2001). In other words, new farming technologies are expected to allow farmers to do more with less. Benbrook (1999) on the other hand reported a decrease in net returns from the use of Ht soybeans.

The US soybean production system has since the seventies seen a tremendous growth in the use of the glyphosate herbicide (Roundup) as a burn-down treatment, used to kill weeds before planting. This has for sometime now served as a relief for soybean growers who were hitherto plagued with an acute weed problem in their soybean fields. Following advent of the Roundup herbicide and its extensive use was the introduction of Roundup Ready soybean (RR soybean) technology in 1996. The popularity of this new soybean seed technology has been attributed to the simplicity of the associated weed control program which allows soybean growers to use one herbicide to control a wide range of both broad and narrow range weeds without causing crop injury. Furthermore, it has also been found to be easy to use with other environmentally friendly tillage practices such as no-till and other tillage practices that farmers are currently using.

Proponents of RR soybean have also identified potential cost savings in adopting the RR soybean technology. Previous studies on the impacts of GM crops include; Gotsch and Wohlgenant (2001), Carpenter et al. 2002, Traxler et al. 2003, Qaim and Zilberman (2003) and more recently Lence, S. H and Hayes, D.J. (2005) and Sobolevsky et al. (2005). Although the economic impact analysis of RR soybeans have previously been studied by a number of researchers (Moschini et al. 2000; Price et al. 2001 and Falck-Zepeda et al. 2000) our paper contributes to the worth of knowledge by providing welfare estimates for comparison with other findings.

In this paper, we exploit the use of a welfare model (the economic surplus approach) as a tool to determine the economic impact of the adoption of Roundup Ready soybeans. A number of methods including the econometric approach and programming techniques have been used to conduct impact assessment analysis in many *ex-post* studies. However, our choice of methodology stems from the fact that the economic surplus approach requires the least data, is relatively easier to use and yields reliable results.

In the first section of this paper, we use a graphical approach to illustrate the benefits of adopting RR technology. The analysis shows the welfare benefits gained by producers and consumers, from a technology-induced supply shift. The case of a parallel and pivotal supply shift due to the adoption of the new innovation is considered.

Market Impact Assessment using the Basic Economic Surplus Method

The economic surplus method provides a relatively simple, flexible approach to investigating the value of adopting new technologies by allowing for the comparison of the results of situations with and without the use of the new technology. The concept of economic surplus used here represents the difference between the monetary value of the units consumed and the monetary value of units produced up to the equilibrium price and quantity. This allows for the comparison of economic surpluses for producers and consumers for a situation where a new technology is used and one where a new technology is not used. However, it is worth noting that a few shortcomings have been identified with the economic surplus method (Alston et al., 1995). For example, it has been criticized for: (i) involving implicit value judgments in the process of estimating research benefits and costs; (ii) ignoring transactions cost that arise due to asset fixity (sunk-cost) and (iii) being a partial equilibrium analysis and ignoring any effects of changes in other product and factor markets in the economy.

In spite of the criticisms stated above, the objective of this section is to use the welfare methodology to estimate the economic surplus gained by producers and consumers that is attributable to the adoption of RR soybean technology. Subsequently, as a working hypothesis, it is maintained here that there is a net increase in economic surplus resulting from the adoption of RR soybean technology.

Major Assumptions of the Model

Unlike Alston et al. (1994) who measure the benefits from research by the shift of an estimated production function, this study follows the Alston et al. (1995) model and assumes a shift of the supply curve following the adoption of RR soybean technology. It is also assumed here that the functional form of the supply curve is unknown. A number of researchers including Voon and Edwards (1992) and Mills (1998) have suggested that when the functional form of the supply and demand curves are unknown, they can be approximated by linear functions. Furthermore, Alston and Wohlgenant (1990) have also shown that especially with parallel shifts, the choice of the functional form has little effect on either the size or distribution of benefits and hence is relatively unimportant. The case of a competitive market is considered and the market price of soybean is fixed and determined through the interaction of demand and supply forces. It is also assumed that the rest of the world (ROW) does not adopt the new soybean technology. However, the U.S. is considered to be a large innovating country which exports either the raw soybean product or the joint products (soybean meal or oil), which are intrinsic characteristics of the soybean market.

In conclusion, from economic theory we appeal to the intuitive notion that the adoption of the new technology (which is cost-reducing or yield-enhancing) generates a rightward shift of the supply curve. The supply shift may be either parallel or pivotal. Both of these two cases will be considered. The demand curve however, is assumed to be invariant to the adoption of the new technology although it could shift over time due to changes in population and income.

Supply and Demand Curves

In order to turn agronomic data to economic values, the surplus approach uses the concept of supply and demand in partial equilibrium. From economic theory, it is known that the supply function may be derived from production costs. Subsequently, recognizing that production levels depend on the use of a wide variety of inputs (e.g. labor, land fertilizer seeds and capital) with associated cost of usage to the producer, producers will increase their output provided a higher output or product price makes his marginal benefit (of increasing input use for higher output) exceed the marginal cost. This results in an upward sloping supply curve indicating a positive relationship between price and quantity. The supply function is however not only affected by price but also by any factor that could modify the cost of production and shift the curve. Thus, the adoption of a new technology can invariably, influence the supply curve. Thus, the initial linear supply curve is given by: $Q^s = \alpha + \beta P$, (1)

where Q^s is the initial quantity supplied, α is the intercept of the supply curve, with β as the slope parameter of the supply curve, and P the price level.

Furthermore, from economic theory, it is known that the demand function is derived from the constrained maximization of the utility function. Given that the quantities consumed depend on the prices paid for the good, it is evident that a higher price will induce consumers to consume less of a good. This yields a downward sloping curve that measures the consumer's willingness to pay for a good. The demand function can thus be influenced by changes in taste, population and income among others. However, it is important to note that the total demand for soybeans in this study is a derived demand determined by (i) the consumer demands for products utilizing soybeans as an input in their production process (such as the demand for soy oil and meal), and (ii) the supply of other inputs used in the various production processes. In other words, the greater the consumer demand for soy oil, for instance, the greater the demand for soybeans used in the production of soy oil and the greater the total demand for soybeans.

The initial demand curve is therefore described mathematically by the following:

$$Q^d = \mu + \gamma P, \tag{2}$$

where Q^d is the initial quantity demanded, μ is the intercept of the demand curve, and γ is the slope of the demand curve.

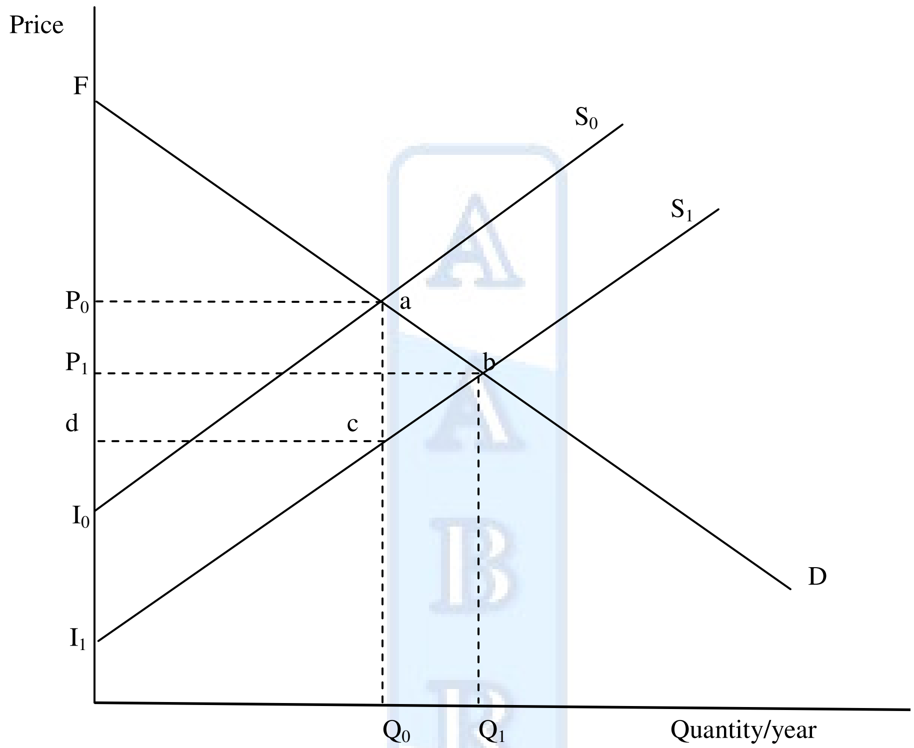
Functional Forms of Supply and Demand:

Researchers commonly use the linear and the constant elasticity supply and demand curves in the estimation of research benefits. Others have also suggested the use of kinked supply curves to avoid the erroneous inference that there could be a positive supply at negative prices for a situation where supply is inelastic and linear (Rose, 1980; Norton et al., 1987). A review of studies of research benefits by Alston et al. (1995) reveals that the majority of such studies use similar assumptions. However, Alston and Wohlgenant (1990) argue that when a parallel shift is used, as suggested by Rose (1980), the functional form is largely irrelevant, and that a linear model provides a good approximation to the true (unknown) functional form of supply and demand. Alston et al. (1995) pointed out that there is no practical difference in using a linear supply curve with or without a kink in analyzing research benefits since the economic surplus is the same in both cases. Consequently, in spite of its criticism, the linear functional form is used in this study especially since the assumption of linearity allows the use of simple algebra to calculate the measures of consumer and producer surplus as presented by Alston et al. (1990).

Measuring the Economic Surplus Given the Nature of the Induced Supply Shift

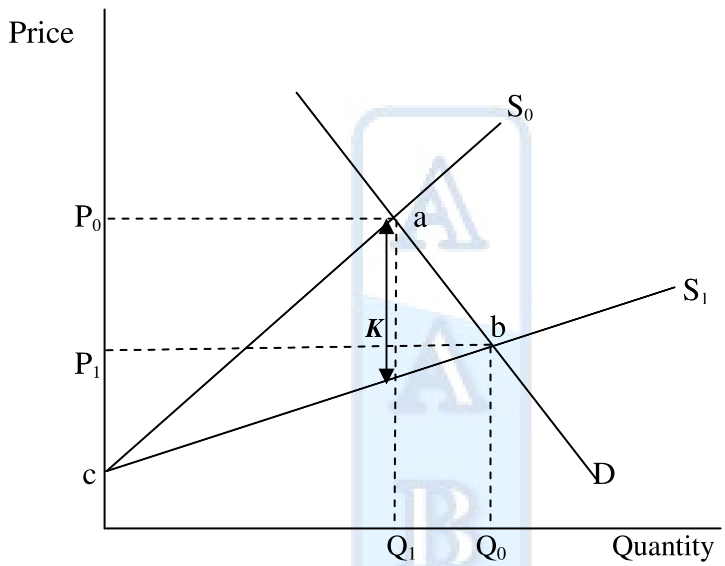
In figure 1a below, the supply curve for soybean production using traditional seeds and conventional farming techniques is denoted by $S_{0,}$ and the demand curve is D.

Figure 1a: The Distribution of Welfare Benefits for a Parallel Supply Shift



The initial price, quantity supplied and demanded are P_0 and Q_0 respectively. As can be noted the total consumer surplus from the consumption of soybean is equal to FaP_0 while the producer surplus is equal to P_0aI_0. The total surplus (the sum of the producer surplus and consumer surplus) is represented by the triangle FaI_0. However, with the adoption of new yield-enhancing and cost-reducing farming technology, the supply curve is expected to shift out S_1. This results in a new equilibrium price and quantity P_1 and Q_1 respectively. The resultant change in consumer welfare (surplus) is then given by the area $P_0ab\ P_1$ and the area P_1bI_1- P_0aI_0 represents the change in producer surplus. In effect consumers gain since they consume more at a relatively lower price however the net welfare effect on producers (area $P_1bcd = P_1bI_1 – P_0aI_0$) may be positive or negative depending on the supply and demand elasticities and the nature of the technology-induced supply shift Alston et al. 1995. For example, if demand is inelastic, an outward shift of the supply curve will result in producers selling more soybeans but at a lower price. This will lead to a decrease in farmers' revenue in this instance as supply increases. Furthermore, Alston et al. 1995 have argued that if the outward shift of the supply curve is pivotal (as in figure 2b) and not parallel, then for an inelastic demand curve, producers are likely to experience greater revenue losses. It has also been noted by Alston et al. 1995 that the total benefits from a parallel shift are twice the size of total benefits from a pivotal shift. Lindner and Jarrett (1978) have also provided evidence to show that with a pivotal supply shift, producers lose when demand is inelastic, however, they may gain or benefit if demand is elastic. This therefore supports the notion that the nature of the supply shift can have some implications on the distribution of welfare benefits resulting from the adoption of the new technologies.

Figure 1b. The Distribution of Welfare Benefits for a Pivotal or Proportional Supply Shift



With reference to the discussion in the earlier paragraph, figure 1b above shows the case of a pivotal supply shift following the adoption of RR soybeans. The consumer surplus increases by the area P_0abP_1 while the producer surplus also changes by the area P_1bc **–** P_0ac**.** The total change in surplus is measured by P_0abP_1+ P_1bc **–** P_0ac**,** the area delimited by S_0, S_1, and D.

From the preceding discussion, it seems reasonable to assume that with the adoption of RR technology, and the subsequent outward shift of the supply curve, the technology-induced change can be treated as an intercept change (a shift factor *k*) in the supply curve and the respective quantity supplied and quantity demanded equations can be written as:

$$Q_r^{\ s} = \alpha + \beta(P+k) = (\alpha + \beta k) + \beta P, \tag{3}$$

$$Q_r^{\ d} = \mu + \gamma P, \tag{4}$$

where $k=(P_0-d)$ is the downward shift of the supply curve due to technology-induced cost saving from the initial market equilibrium price before the supply shift P_0.

This implies that using the market clearing conditions:

$$\sum Q^d = \sum Q^s \qquad \text{(Without new technology)} \tag{5}$$

$$\sum Q_r^{\ d} = \sum Q_r^{\ s} \qquad \text{(With the adoption of new technology)} \tag{6}$$

The market equilibrium prices with adoption and without adoption P^{r*} and P^* respectively can be given by:

$P^* = (\mu - \alpha)/(\beta + \gamma)$ when $k=0$ (7)

and $P^{r*} = (\mu - \alpha - K\beta)/(\beta + \gamma)$ where $K=k/P_0$ (8)

This implies that the research-induced change in price is given by:

$P^* - P^{r*} = (K\beta)/(\beta + \gamma).$ (9)

Converting the slopes in equation (9) into elasticities[1], the equilibrium market price that results when the new technology is adopted is: $P^{r*}=P_0\{1-(K\varepsilon)/(\varepsilon+\eta)\}$, (10)

where ε is the elasticity of supply and η is the absolute value of the price elasticity of demand. Following Alston et al. (1995), the relative reduction in price is also defined as: $Z = -(P_1-P_0)/P_0= (K\varepsilon)/(\varepsilon+\eta)$ and $(Q_1-Q_0)/Q_0=Z\eta$. Therefore with the adoption of the new technology, the new equilibrium price and quantity can be written as:

$P^{r*}=P_0(1-Z)$, (11)

$Q^{r*}=Q_0(1-\eta Z)$. (12)

The gains in the consumer surplus can therefore be derived and expressed algebraically as: $\Delta CS = (P_0 - P_1^{r*})[Q_0 + 0.5(Q_1^{r*} - Q_0)]$, (13)

and the corresponding change in producer surplus is also given by:

$\Delta PS = (k + P_1^{r*} - P_0)[Q_0 + 0.5(Q_1^{r*} - Q_0)]$[2]. (14)

It can therefore be shown by substituting equations (11) and (12) into equations (13) and (14) that the algebraic expressions for estimating the changes in the economic surplus for a parallel shift are as follows:

$\Delta CS = P_0 Q_0 Z(1 + 0.5Z\eta]$, (15)

$\Delta PS = P_0 Q_0 (K - Z)(1 + 0.5Z\eta]$, (16)

$\Delta TS = \Delta CS + \Delta PS = P_0 Q_0 K(1 + 0.5Z\eta]$ (17)

Regarding the measures for assessing the economic benefits for a pivotal shift, it is important to note that studies show that a proportional shift is roughly half the measure obtained with a parallel shift in supply (Lindner and Jarrett 1978; Gotsch and Wohlgenant 2001; Alston et al., 2004). Notwithstanding, deriving the formulae for calculating the economic surpluses from a pivotal shift of the supply curve can be confusing. However, Ulrich, Furtan and Schmitz (1986), Norton, Ganoza and Pomareda (1987) and most recently Gotsch and Wohlgenant (2001) have derived the mathematical formulae needed to calculate the respective areas for a pivotal supply shift as the following: $\Delta TS = 0.5 P_0 Q_0 K(1 + Z\eta]$[3] (18)

and $\Delta CS = P_0 Q_0 Z(1 + 0.5Z\eta]$[4]. (19)

Subsequently after using the general representation in Ulrich, Furtan and Schmitz (1986), we can then calculate the change in producer surplus as:

$\Delta PS = \Delta TS - \Delta CS$, (20)

[1]For proof see Alston et al., 1995, p. 211

[2]A reference to Alston et al., 1995, p. 211 also shows that the expression $(k + P_1^{r*} - P_0)$ is equivalent to (P_1-d) in the figure 1a above.

[3,4]See Linder and Jarrett, 1978 for proof of formula.

where $K=k/P_0$, is defined as the supply shift relative to the initial equilibrium in other words, it is the proportionate vertical shift down in the supply curve due to a cost reduction realized from the adoption of the new technology (RR soybean technology).

Model with International Trade

In the basic model, we assumed a closed economy and hence no price spillovers. However, given that the U.S. soybean industry is marked with extensive international trade and that soybeans are not exclusively produced and consumed domestically, we extend the basic model to incorporate the possibility of trade between the U.S and the rest of the world (ROW). The U.S. is assumed to be a large exporting country (open-economy) that also initiates and adopts new soybean technology (RR soybean varieties) while the ROW does not adopt the new technology.

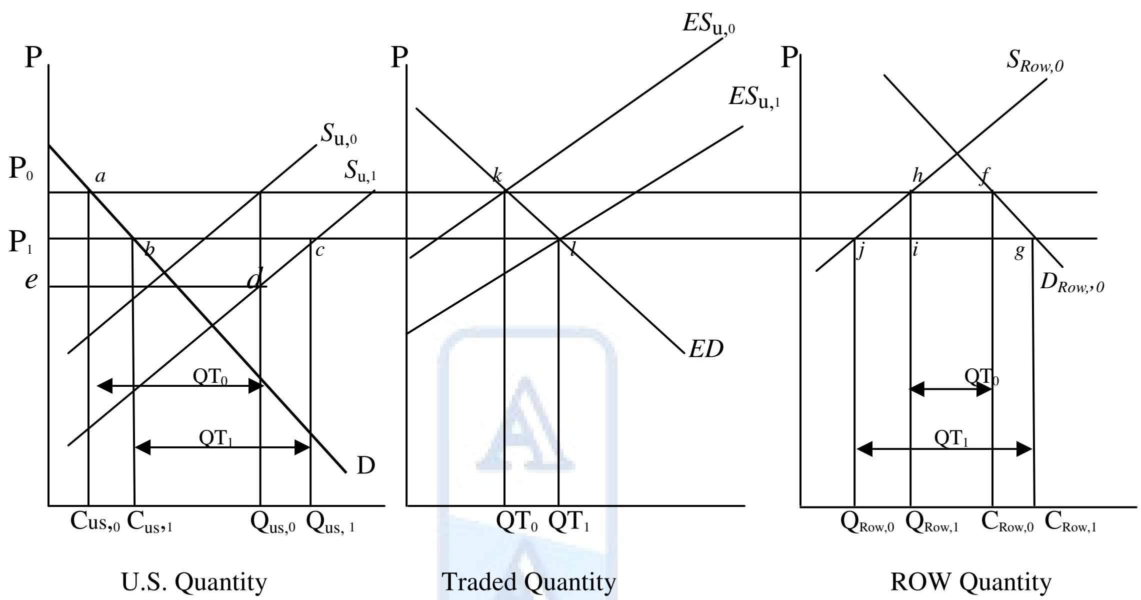
Other important assumptions in the foregoing analysis include the fact that there is no technology spillover but price spillovers are present and a linear supply and demand curve with a parallel and a pivotal shift of U.S. supply from the adoption of the new technology is assumed and analyzed respectively. It is subsequently assumed that the U.S. can affect world prices through its exports. Therefore it is expected that the gains or loss from the supply curve shifts will affect other countries as well. Finally, we assume that the law of one price holds in this model. Therefore a single equilibrium world price is assumed in the model hence all regions in the U.S. are faced with the same price and that regional prices differ only by transportation costs.

The Empirical Model

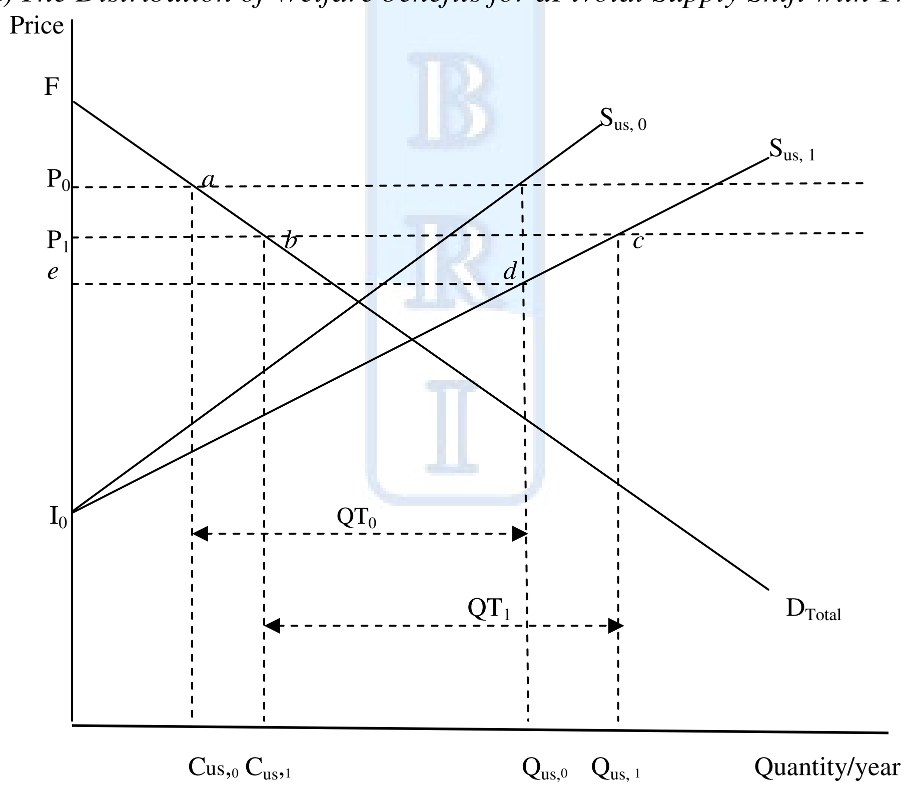
We model the world soybean market for trade between the U.S. a large open economy, and the ROW where the market clearing condition is ensured by equating excess supply and excess demand. The surplus distribution resulting from adoption and trade of soybean produced in U.S. which results in a parallel supply shift is presented graphically in figure 3 below.

Figure 3. Marshallian Economic Surplus Distribution

(a) U.S. production, consumption & trade (b) Excess supply, demand & trade (c) ROW production, consumption & trade



(d) *The Distribution of Welfare benefits for aPivotal Supply Shift with Trade*



In figure 3 above, panel (a) represents the U.S. soybean supply and demand while panel (c) presents the aggregate supply and demand in the ROW. The excess (export) supply of soybeans in U.S. is shown as $ES_{us,o}$ in panel (b). This obtained by taking the horizontal difference between the initial domestic supply ($S_{us,o}$) and the demand ($D_{us,o}$) in panel (a).

On the other hand, the initial excess (import) demand of soybean from the ROW labeled as *ED* in panel (b) which is equal to the volume exported by the U.S. This is the horizontal difference between the ROW demand ($D_{ROW,o}$) and supply ($S_{ROW,o}$). Subsequently, the international market equilibrium for the soybean market occurs when the excess supply and excess demand curves intersect at the price P_0.

We also define Q_{us} and C_{us} as the U.S. domestic soybean quantity produced and consumed respectively and Q_{To}, the soybean exports. Similarly $Q_{ROW,o}$ and $C_{ROW,o}$ are also considered to represent the ROW quantities of soybean produced and consumed respectively with Q_{To} in panel (c) being the amount of soybean imports.

With the adoption of a new soybean technology by the U.S. and a subsequent outward shift of the U.S. domestic supply curve, a movement from $S_{us,o}$ to $S_{us,1}$ results. This causes the excess supply to shift from the initial $ES_{us,o}$ to the new $ES_{us,1}$ curve resulting in the establishment of a new equilibrium price P_1 and the corresponding new domestic equilibrium quantities shown in figure 3 as soybean production $Q_{us,1}$, exports Q_{T1}, and consumption $C_{us,1}$.On the other hand the new ROW quantities that results due to the supply shift, is indicated in the graph as production $Q_{ROW,o}$, imports Q_{T1}, and consumption $C_{ROW,1}$.

Clearly our analysis so far predicts some possible gains and losses due to the adoption of the new technology by the U.S. and the subsequent exports of soybeans by the U.S. to the ROW. World soybean prices are also likely to fall following the phenomenon described. The following regions indicate the predicted economic surpluses by producers and consumers of soybean in both regions. The area P_0abP_1 designates the U.S. consumer surplus change, P_1cde represents the U.S. producer surplus change, P_0hfgj is the ROW consumer surplus change, P_0hjP_1 is represents the ROW producer surplus change and the net ROW surplus change is shown by the area P_0klP_1.

To conclude the discussion on figure 3 above, we note that the diagram in panel (d) depicts an alternative view of the soybean complex presented in panel (a) and traces the economic surplus distribution for the case where there is a pivotal shift of the supply curve instead of a parallel shift in a large-open economy. It is however important to note that even though the designation of regions representing producer and consumer surpluses is the same as in the discussion under the closed economy case, following the discussion in Piggott and Wohlgenant (2002) we infer that the demand faced by U.S. producers is actually the total demand (domestic and export demand) and not just the domestic as assumed by other studies.

Estimated Equations when Trade is Incorporated into the Model

To estimate the economic surpluses discussed in this study, we follow the model proposed in Alston, Norton and Pardey 1995, p. 216. In this case, unlike the basic model, we introduce international trade in the model. It is assumed that the ROW supply of soybeans does not shift since the ROW does not adopt the technology. As presented, the U.S. and the ROW supply and demand functions are modeled using the following equations:

U.S. domestic supply: $Q_{us} = \alpha_{us} + \beta_{us}(P + k) = (\alpha_{us} + \beta_{us}k) + \beta_{us}P,$ (21)

U.S. domestic demand: $C_{us} = \gamma_{us} - \delta_{us}P,$ (22)

ROW supply: $Q_{ROW} = \alpha_{ROW} + \beta_{ROW}(P + k)$, (23)

ROW demand: $C_{ROW} = \gamma_{ROW} - \delta_{ROW}P$. (24)

In this model it is assumed that the introduction and adoption of the new soybean technology shifts the supply function vertically by a factor k through cost-savings upon adoption. P is the equilibrium world price of soybean and Q_{us} is the quantity of soybean produced while C_{us} is the amount of soybean consumed (which may include RR soybean and or conventional varieties) in the United States. Similarly, C_{ROW} and Q_{ROW} are the quantities of soybeans consumed and produced by the rest of the world.

Using the identity $Q_{us,0} + Q_{ROW,0} = C_{us,0} + C_{ROW,0}$, the trade equilibrium, $QT_0 = C_{ROW,0} - Q_{ROW,0} = Q_{us,0} - C_{us,0}$ is established and assumed in the model. Alston et al. (1995) algebraically shows that the counterfactual world price P_0 (the price that would have prevailed if the new soybean technology had not been introduced) and the relative price change Z, can be calculated by expressing the formulae in elasticities as shown below:

$P_0 = P_1 / \{1 – (\varepsilon_{us}K / [\varepsilon_{us}+S_{us}\eta_{us}+(1- S_{us})\eta^{ED}])\}$, (25)

and $Z = -(P_1 – P_0) / P_0 = \varepsilon_{us}K / [\varepsilon_{us}+S_{us}\eta_{us}+(1- S_{us})\eta^{ED}]$, (26)

where $K=k/P_0$ with the adoption or introduction of RR soybean and the subsequent supply shift. The parameter K also allows for the conversion of the absolute price shift to a percentage reduction in price. The parameter ε_{us} is the U.S elasticity of supply for soybeans, η_{us} is the absolute value of the U.S. price elasticity of demand for soybean, the term η^{ED} on the other hand is the absolute value of the elasticity of export demand or the ROW excess demand elasticity (η_{EROW}), finally the term S_{us} is the share of the U.S soybean production that is consumed domestically. Adapting the formulae for calculating the economic surplus changes from Alston et al. 1995, p. 217, we applied the following to compute the consumer and producer gains and losses:

$\Delta PS_{us} = P_0Q_{us,0} (K_{us}-Z) (1 + 0.5 Z \varepsilon_{us})$, (27)

$\Delta CS_{us} = P_0C_{us,0} Z (1 + 0.5 Z \eta_{us})$, (28)

$\Delta PS_{ROW} = -P_0Q_{ROW,0} Z(1 + 0.5 Z \varepsilon_{ROW})$, (29)

$\Delta CS_{ROW} = P_0C_{ROW,0} Z (1 + 0.5 Z \eta_{ROW})$, (30)

$\Delta S_{ROW} = \Delta CS_{ROW} + \Delta PS_{ROW}$. (31)

As discussed earlier, the equations for the pivotal shift of the supply curve in the large open economy case also follows the calculations presented in Ulrich, Furtan and Schmitz (1986). With a little manipulation of the general formula provided in the paper, this yields the following formulae:

$\Delta TS_{us} = 0.5P_0Q_{us,0} K_{us} (1 + Z \eta_{us})$, (32)

$\Delta CS_{us} = P_0C_{us,0} Z (1 + 0.5 Z \eta_{us})$, (33)

$\Delta PS_{us} = \Delta TS_{us} - \Delta CS_{us}$. (34)

A Graphical Representation of Cost and Shifts due to New Technology Adoption

In a recent paper, Alston, Marra, Pardey, and Wyatt (2000) indicated that the nature of the research-induced shift and the percentage research-induced reduction in cost of production (k), following the adoption of a technology among others, are critical determinants in measuring the benefits from a particular activity.

A summarized graphical representation of the gain in output per unit input used (horizontal shift of supply curve) and a change in input cost (a vertical shift) that results from the adoption of the new technology is shown in the figure below.

Figure 4. Cost-Reduction and Output Gain from a Technology-Induced Supply Shift due to RR Soybean Adoption

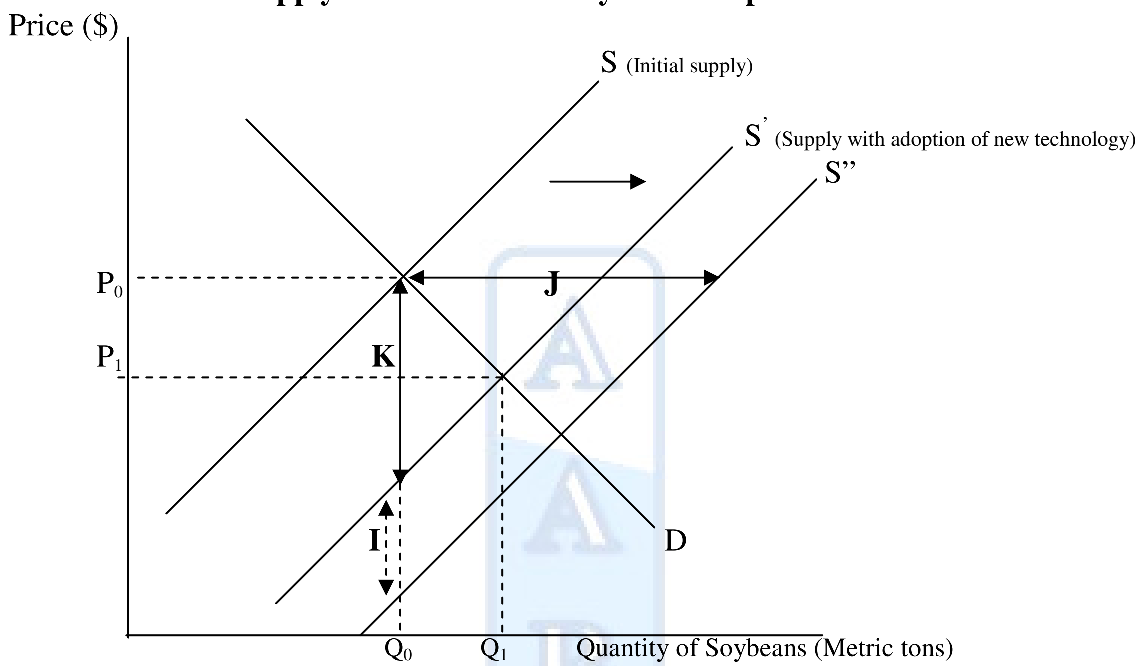


Figure 4, briefly summarizes the parameters that must be estimated and generally suggests the data that are needed in order to assess the market impact of the adoption of the new technology (RR soybeans). While the ***K*** parameter represents the net gain in terms of a decrease in production costs, and **J** is the output gained, it is argued that if the new technology were adopted at no cost, then the *S"* (S+J) would be the with-research supply curve.

However, since the adoption of new technologies typically requires some investment in new inputs (for example, farmers planting RR soybeans may require the purchase of some hybrid seeds and possibly pay technology fees), The vertical distance **I** shown on the graph above represents the adoption costs on a per unit basis (i.e. $/kg). Subsequently, taking both **J** and **I** into account leads to the net shift in the supply curve from S to S'.

Calculating the Economic Surplus

From the graphical approach presented above it is important to derive the precise mathematical formulae needed to calculate the surpluses since the parameters *K, J* and *I* are not directly observable but can be estimated using available data. As discussed in detail in Alston et al. (1995), the calculation of the economic surplus requires that certain necessary parameters ought to be estimated. This include the following: the increase in productivity (ΔY) in kg/ha, adoption cost (ΔC), adoption rate (t) in terms of percentage increase in acreage allocated to the activity (or in terms of new entrants), total acreage planted (A) in hectares, total production (Q) in metric tons, and average yield production/productivity (Y=Q/A). Data for acres planted, yield, adoption rates and costs were estimated from the results of a survey of RR soybean adoption conducted in 2002 on 610 soybean farmers. Using the information above, we estimated the *K, J* and *I* parameters as discussed in the succeeding sections.

The J Parameter (Production Increases):

This parameter is considered to be the total increase in production that is caused by adopting the new technology, holding the price and change in costs constant. From the survey results the following parameters were calculated and used; the yield increases (ΔY) due to the adoption of the RR soybean technology which was estimated to be $1.12 bushels/acre, a 72% adoption rate (t) which was computed as the proportion of the total area under the new technology (RR Soybeans), and a total soybean acreage (A) of 1153.56 acres.

By definition: $J = \Delta Y * t * A$. (33)

To allow for the calculation of the change in supply or the coefficient by which the supply curve moves with the new technology, we compute the J parameter in proportional terms as the increase in yield or quantity produced as a share of the total quantity. Hence J can be transformed into: $j = J/Q$. (34)

This allows the estimation of the supply shift parameter (j) in terms of the yield gains, adoption rates and the overall average soybean yield (Y=Q/A). Thus, $j = (\Delta Y * t)/Y$.

The I Parameter (Adoption Costs):

The parameter *I* is define as the increase in per-unit input costs necessary to gain the (J) production increase. We use the adoption cost (ΔC), per unit of the acreage switched to the new technology, the adoption rate (t) and the overall average yield (Y) to calculate this cost. The formula applied is therefore:

$I = (\Delta C * t)/Y$. (35)

As a means of convenience, (I) is calculated in proportionate terms as the increase in cost (I) as a share of the observed price (P). The proportional cost increase parameter (c) is therefore expressed as: $c = I/P = (\Delta C * t) / (Y*P)$. (36)

The K Parameter (Vertical Shift of the Supply Curve):

As defined earlier, the net reduction in production cost (from the combined effects of increased productivity, *J* and adoption costs, *I*) induced by the adoption of the new technology is theoretically computed using the slope of the supply curve (∇) as: $k= \{J * \nabla \}- I$. (37)

However, in practice the slope (∇) is not used; researchers use the supply elasticity (ε) instead. Therefore because $\varepsilon = \% \Delta Q / \%\Delta P = (\Delta Q / \Delta P) * (P / Q)$, it follows that:

$\varepsilon = (1 / \nabla) * (P / Q)$.

Thus, $\nabla = (1/\varepsilon) * (P / Q)$. (38)

Therefore using equation (37) above, $k= [J * (1/\varepsilon) * (P / Q)] – I$, (39)

but $J = j * Q$. Therefore equation (37) becomes: $k = \{(P * j) / \varepsilon\} – I$.

Subsequently for the net reduction in production costs as a proportion of the product price, the equation above becomes: $k/P = \{(P * j) / \varepsilon\}/P – (I / P)$, (40)

and $K= (j / \varepsilon) – c$. (41)

The data sources for these computations range from primary to secondary data. Subsequently, the information on data used include market level data for prices and quantity, field data for adoption rate, yield and input change and some economic parameters including demand and supply elasticities etc.

Compiling Data for Economic Surplus Computation

In the previous section we discussed the basic formulae and data needs used to compute the surplus distribution with the introduction of the new RR soybean technology. This section will thus discuss the data sources used for the analysis. Generally, data were collected from national statistical sources, e.g. USDA World Agriculture and Trade Tables, the FAO production yearbook and other information were gathered from the survey conducted and estimates from previously published studies.

Elasticity of Supply and Demand:

Data for the elasticities of demand and supply were obtained from published results of previous studies. The data on the price elasticities of demand is adopted from Piggott and Wohlgenant (2002). This is relevant to the current study since the assumptions of this model allows for the possibility of trade in the joint products of soybean (soybean meal or oil).

By extending Houck's insightful analysis for derived demand elasticities of joint products, Piggott and Wohlgenant (2002) used the U.S. soybean industry as an example to demonstrate that while the derived price elasticity of domestic demand retains the same form as Houck (1964) shows in his publication, when the possibility of trade in the joint and raw soybean products was introduced into the model, the relevant price elasticities of demand are the elasticities of total demand for soybean meal and soybean oil (where total demand equals the domestic demand plus the export demand) instead of just the domestic demand elasticities. Subsequently, by adopting the calculated price elasticities of demand provided in Piggott and Wohlgenant (2002), it is argued following the authors that, allowing for trade especially in the joint products of soybean results in a more elastic demand (for proof see Piggott and Wohlgenant, 2002). This assumption therefore alters and justifies the nature of the price elasticity of demand for soybeans used in the current model i.e. -0.29.

On the other hand, the domestic soybean supply elasticity used in this estimation is retrieved from Jiang et al. (2001). After an econometric estimation of the demand and supply equations, the author estimated the U.S supply elasticity of soybean to be 0.14 and the ROW supply elasticity of soybean to be 0.09. Other elasticities obtained from previous studies for the current study include; U.S. export demand elasticity (-0.94) as estimated by Piggott and Wohlgenant (2002), and the ROW soybean demand elasticity used is -0.04 which was taken from Jiang et al. (2001).

Market Data on Prices and Quantities:

Since the current study assumes a competitive market with no price or quantity restrictions (e.g. import quota), the data collected on the parameters in question was not complicated. Basically the data on the price of soybeans was taken from the USDA (United States Department of Agriculture) National Agricultural Statistical Service and that for quantities produced and consumed were taken from the World Agricultural Supply and Demand Estimates and USDA Fasonline for the period 2001/2002.

Cost of Adoption:

The data on the cost of adoption used for this study was taken from the information provided by survey respondents. Our 2002 survey conducted on 610 US soybean farmers revealed an estimated average costs per acre for Roundup Ready soybean seed, harvesting, herbicide material and application to be \$24.14, \$19.26, \$15.36 and \$6.01 respectively. Similarly, for traditional soybeans costs calculated, were \$14.98, \$18.99, \$23.94 and \$7.02 respectively

Results and Discussion

This section presents the results of the market impact analysis of adopting RR soybeans in 2002. The current study does not include analysis on the impact of adopting no-till technology because of lack of adequate data on the costs involved in adopting no-till. The results include the changes in economic gains to producers and consumers in a large-open economy. We do not include the analysis of economic surplus gains by farmers in different regions nor do we report the welfare benefits of a monopolist such as Monsanto Corporation. The result is also presented for different supply curve shifts (Parallel or pivotal shifts). Table 1 below presents the estimated economic surplus and the respective shares of the total world surplus that goes to producers and consumers in the U.S. and the ROW.

Table 1. Estimates of the Economic Surplus Distribution for the Adoption of RR Soybean Varieties in the U.S. in 2002 (Open Economy)

	Parallel (% of Total World Surplus)	**Pivotal** (% of Total World Surplus)
U.S Consumer Surplus	$1.1million (13%)	$1.1million (23%)
U.S. Producer Surplus	$6.7million (82%)	$3.1million (68%)
U.S. Total Surplus	$7.8million	$4.2million

Table 1. Continued:	**Parallel** (% of Total World Surplus)	**Pivotal** (% of Total World Surplus)
ROW Consumer Surplus	$2.4million	$2.4million
ROW Producer Surplus	-$1.97million	-$1.97million
Net ROW Surplus	$0.43million (5%)	$0.43million (9%)
Total World Surplus	$8.21million	$4.64million

In Table 1 the results of a large-open economy are presented. Surplus estimates using the Alston, Norton and Pardey (1995) approach shows that for a parallel shift of the supply curve, while both consumers and producers in the U.S. gain in their economic surpluses, the size of the producer surplus is quite incomparable to that of the consumer surplus. In other words, while U.S. producers had an increase in benefits of about $7 million, U.S. consumers gained only $1 million, which indicates that US producers gained about 7 times more than U.S. consumers with international trade for a parallel shift. Furthermore, with a parallel shift of the supply curve in a large open economy, whereas the ROW consumers gained approximately $2.4million, producers in the ROW lost an estimated $2million in surpluses due to the downward price pressure from the additional soybean output from the United States. With a pivotal shift in the large-open economy, the U.S. consumer surplus gain is about $1 million while the change in U.S. producer surplus is an estimated $3 million yielding a change in total of approximately $4 million which is about half the change in total surplus for the parallel shift. The net change in the rest of the world surplus in both cases (parallel and pivotal) is estimated to be about $0.4 million.

Summing the welfare effects for producers and consumers in each sector yields the changes in total surpluses. It was realized that for a parallel shift the increase in total surplus is about $7.8 million while $4.2 million was the estimated amount for a pivotal shift. The total increase in world surplus from the adoption of RR soybean varieties in 2002 is calculated to be approximately $8.21 million for a parallel shift and an estimated

$4.64 million for the pivotal shift in the open economy case. Of this total, the largest share of 82% (parallel) and 68% (pivotal) went to U.S. producers. U.S. consumers with 13% and 23% of total world surplus gained for a parallel and pivotal shift respectively also received the next largest share. Finally, the rest of the world received the smallest share of the total world surplus, which was approximately, 5% for the parallel case and 9% for the pivotal supply shift. Clearly, this shows that the introduction and adoption of the new seed technology improved the competitive advantage of farmers in the United States through higher yields and cost savings. On the other hand, the increased output or supply of soybeans in the world market also benefited consumers in both sectors especially those in the ROW through the prevalence of a lower soybean price in the world market. As it were, the surplus gain of the consumers in the rest of the world exceeded that the losses of the ROW producers. It is also worth noting that two reasons may explain why the producers in the rest of the world realized welfare losses: the first reason may be attributed to the widespread production of conventional soybean varieties in the rest of the world without the yield advantage and /or cost savings associated with RR soybeans, and secondly, the exposure to lower prices caused by the rapid adoption of RR soybean varieties in the United States.

While the farm-level effects used in our calculations were relatively smaller compared to that of other studies, adopters of RR soybeans may have realized other benefits that have not been quantified in this study, for example those arising from the simplicity and flexibility of weed control programs, fewer restrictions on crop rotation, and synergy with conservation tillage systems (Fernandez-Cornejo and McBride, 2002) as well as some other non pecuniary benefits that have not been quantified nor accounted for as reported by Marra, Piggott and Carlson (2004).

Conclusion

The goal of this study has been to estimate the changes in the Marshallian surplus for producers and consumers in the United States and the rest of the world. The case of a parallel and pivotal supply shift was considered and the relevant formulae needed to calculate the surplus measures were developed and discussed. We find that while consumers and producers in the United States gain from the adoption of the new soybean technology, the consumer gains in the rest of the world of $2.4 million is offset by the losses realized by producers in the rest of the world (-$1.97 million) leaving a net ROW surplus of $0.43 million. Consumers in the ROW gained from the worldwide lower commodity prices due to the adoption by the United States. Producers in the ROW lose due to the continuous cultivation of traditional soybean varieties which is not associated with high yield advantages nor cost- savings coupled with the prevalence of lower soybean prices caused by increase in U.S. soybean production. The estimated total world surplus arising from the adoption of RR soybeans varied significantly for the parallel case compared to the pivotal shift case. However, as expected the estimated total surplus for the pivotal supply shift ($4.64 million) was about half that of the parallel shift ($8.21 million). Interestingly U.S. producers obtained more than half of the estimated total benefits in 2002.

One of the weaknesses of the current study is that we do not include the monopoly power of Monsanto Corporation over the production and sale of RR soybeans. It is possible that a greater portion of the U.S. producer surplus goes to Monsanto in the form of monopoly profits. However, this opens an opportunity for future extensions of the current study. Another possible extension of this market impact analysis is the possibility of incorporating the value of non-market benefits (non-pecuniary benefits) such as convenience factors of simplicity and flexibility in weed control systems, the value of human and environmental safety etc. associated with the use of RR soybean. The impact of these non-market benefits may be significant as reported in Marra et al. (2004) and hence might affect the size and distribution of the surpluses in the current analysis. Another shortfall of the current study is that it does not consider the stream of benefits beyond or before the year 2002. This if considered might yield a more accurate analysis and present a better perspective of the true impact of the adoption of the biotech crop (in terms of size and distribution of total benefits). Furthermore with the increased transfer of RR soybean technology to the ROW for example Brazil, Argentina etc. it will be appropriate to extend the model to incorporate technology spillovers and adoption by the ROW. Moreover, how does the possible emergence of other competing biotech crop varieties and affect the use of RR soybean technology and subsequently the size and distribution of benefits. Finally, given the ethical issues surrounding the use of GMOs, it will also be interesting to ascertain how our estimated surpluses will change in a case where consumers in the U.S. boycott or show resistance to the GMO product.

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