ABSTRACT

MENSAH, EDWIN CLIFFORD. The Market Impact of the Simultaneous Adoption of Complementary Agricultural Technologies. (Under the direction of Dr. Michele Marra and Dr. Michael Wohlgenant)

The purpose of this study is to examine the factors that influence the simultaneous adoption of no-till farming technology and Roundup Ready soybean (RR) varieties. The research is also extended to analyze the welfare benefits of the adoption of new agricultural technologies. We first investigate the factors that influence the single adoption of the individual technologies using a feasible generalized least squares (FGLS) estimation method which also allows us to correct for the presence of heteroskedasticity in the model. Given that our dependent variables were the proportion of acres we were also able to use the two-limit Tobit procedure to verify the extent of the adoption of the two technologies. Of the explanatory variables used in this study, farm size, the level of education, experience, convenience factors, cost and yield difference were found to be significant factors in explaining the adoption and the extent of adoption of these technologies.

Furthermore, to answer our question on the simultaneity between the two technologies, we compare the results of two separate single equation probit models for the adoption of the two technologies with that of a simultaneous two-equation econometric model and draw conclusions regarding the endogenous nature of the adoption of the two technologies by constructing a Wu-Hausman test statistic. We infer from our results that in explaining the adoption of the two technologies, accounting for simultaneity is not only important for the no-till decision but the decision to adopt RR soybean varieties as well. We

also found in this study that there is some synergy in the use of the two technologies hence it is concluded that the two technologies are likely to be complementary to each other.

The market impact analysis was achieved by using the Alston, Norton, and Pardey (1995) approach. We assessed the welfare effects of the adoption of RR soybean varieties for both a parallel and pivotal shift of the supply curve. The theoretical model implemented assumes two main regions; a large producer country adopting the new technology (U.S.) and all other countries aggregated into the rest of the world (ROW), the non-adopting region. Although producers and consumers in the U.S. gained a greater share of the total benefits, the economic surplus gained by consumers in the ROW were offset by the producer losses in the ROW. Producers in the U.S. had the greatest share of the total economic surpluses. However, the magnitude of the total benefits greatly depends on the nature of the supply shift. Our results show that the total benefits for a pivotal shift are about half that of a parallel shift.

The Market Impact of the Simultaneous Adoption of Complementary Agricultural Technologies

by

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DEDICATION

This dissertation is dedicated to God,

my parents Mr. E.K. Mensah and Mrs. Christiana Mensah,

mum Milly Taylor, my siblings, my wonderful wife Bessie and my

lovely daughters, Nadia Christiana and Caitlyn Milyneece.

BIOGRAPHY

Clifford Mensah was born in Atibie-Kwahu, Ghana to Mr. and Mrs. E.K. Mensah. At an early stage in his life, his parents instilled in him the values of godly living and christian education. After completing his early childhood education in mostly Seventh-Day Adventist schools, he pursued a degree in the University of Ghana-Legon where he earned a Bachelor of Science degree in Agriculture (plant breeding and genetics) in 1996 and served as a teaching assistant until the fall of 1997. Clifford was then awarded a student scholarship to visit Switzerland for the period 1997-1998.

However, in April of 1998 he immigrated to the United States of America and gained admission into North Carolina State University's MA/Ph.D Program in Economics in 1999. While pursuing his degree Clifford had the privilege of teaching classes in economics to undergraduates where he excelled and won awards in recognition for his excellence in teaching. He is currently teaching at the University of North Carolina at Pembroke but resides in Raleigh, North Carolina with his lovely wife Bessie and two daughters, Nadia and Caitlyn.

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Chapter 1

1. Introduction

Although the percentage of cropland farmed with some sort of conservation tillage has remained fairly constant, no-till acres continue to increase steadily. In fact since 1990 the popularity of no-till farming has grown from 6% to more than 16% of the planted acres in the United States. The 2002 survey report published by the Conservation Technology Information center (CTIC) presented in appendix A, shows that no-till was used on nearly 20% of all cropland acres, compared to 16% mulch-till and 1% ridge-till. Thus, no-till planting systems were used on more than 55 million acres in the U.S in 2002. By crop, no-till soybeans were grown on approximately 35% of cropland acres, no-till corn was grown on about 18% of cropland acres and no-till cotton was grown on about 14% of cropland acres according to the 2002 National Crop Residue Management Survey published by CTIC (appendix B).

No-till farming may be defined as a farming practice where the soil is left undisturbed from harvest to planting. Planting or drilling is accomplished in a narrow seedbed or slot created by disk openers. Coulters, residue managers, seed firmers, and modified closing wheels are used on the drill or planter to ensure adequate seed to soil contact. In a properly designed no-till system, pest (weeds, disease, and insect) control is usually accomplished primarily through crop rotation and the judicious use of herbicides to provide the crop with a competitive advantage over the weeds.

As a soil conservation practice, no-till has been found to be both economically and environmentally beneficial. Some of the benefits of no-till farming include: increased residue, increased soil organic matter, reduced erosion potential, increased water holding capacity, improved soil tilth, reduced bulk density, increased earthworm populations, improved soil structure, elevated infiltration rates, and reduced field time. Proponents of no-till have reported higher yields and profits associated with farms where no-till is practiced even though a number of such farms initially reported lower profits (Sorrenson et al., 1997). The initial lack of adequate information about the new innovation could possibly offer an explanation for this scenario since new technologies tend to require new management skills which farmers might acquire with time through "learning by doing." This, in addition to the farmer's initial investment in new equipment and seed input, may introduce some adjustment costs which may contribute to the lower initial profitability.

It is important to recognize that farmers are rational and expect to make normal profits from their investments. In his seminal paper Griliches (1957) showed that expected profitability positively influences the adoption of agricultural innovations. Therefore factors expected to increase profitability by increasing revenues or reducing costs would generally influence adoption positively. It is therefore reasonable to argue that the decision to adopt no-till could possibly depend on its ability to yield additional net returns in the long run that are equal to, or exceed, the costs of increasing the farmer's debt load to purchase specialized no-till equipment and possibly, increased herbicide costs.

The farmer's decision to adopt no-till is further complicated when faced with the concurrent decision to adopt Roundup Ready (RR) soybean, a new genetically modified crop that has been engineered to be resistant to glyphosate. However, in spite of this dilemma, Roundup Ready soybean adoption is increasing even though prices of herbicides commonly used on conventional soybeans have fallen to the point that when only monetary costs and returns are considered, conventional soybean systems are competitive with Roundup Ready soybean systems (Marra et al., 2004). The question is: why do farmers adopt Roundup Ready soybeans? Specifically, does a farmer's adoption of Roundup Ready soybeans result in a higher propensity to adopt no-till?

Proponents of GMO's (genetically modified organisms) claim that the adoption of Roundup Ready soybean varieties lowers adopters' costs by (a) allowing post emergence use of the inexpensive herbicide glyphosate, (b) saving on management costs because of its simple use, (c) reducing risk by widening the time window for post emergence spraying, and (d) the additional advantage of coupling RR soybean with no-till.

1.1 Research Motivation

Recently Monsanto Corporation introduced a program code-named the "Bottom-Line Booster Guarantee" with the sole goal of encouraging the use of conservation tillage, especially no-till farming, when Roundup Ready soybean is used. The claims of this program briefly discussed in the next section, as well as other success stories reported by farmers and agronomists, motivate the quest for answers to the central question of this research: Does the adoption of Roundup Ready soybeans affect the use of reduced tillage (including no-till)? If it does, what are the welfare implications of the adoption of the new technology? If farmers are adopting these technologies together, what characteristics foster such an adoption? Little has been established regarding the concomitant adoption of technologies and the resulting welfare implications, hence the relevance of the current study.

1.1.1 Monsanto’s Bottom-Line Booster Guarantee

It has been claimed by Monsanto Corporation that "Farmers like the weed control they get with Roundup over the top of Roundup Ready soybeans, but the economic benefits are displayed when farmers use the whole system, including reduced tillage," says Monsanto market manager Kurt Rahe (Southeast Farm Press, 2000). Consequently, in the summer of 2000, Monsanto instituted the “Bottom-Line Booster Guarantee.” Kurt Rahe further argues that "With the Bottom-Line Booster Guarantee, farmers have everything to win and nothing to lose by making the switch to conservation tillage and Roundup Ready soybeans."

The program encourages growers to compare the Roundup Ready soybean system in conservation or reduced tillage to non-Roundup Ready soybeans with conventional tillage and herbicide programs. If the Roundup Ready system does not provide an equal or better net income than the traditional system in the comparison, Monsanto pays each qualified grower up to $10,000.

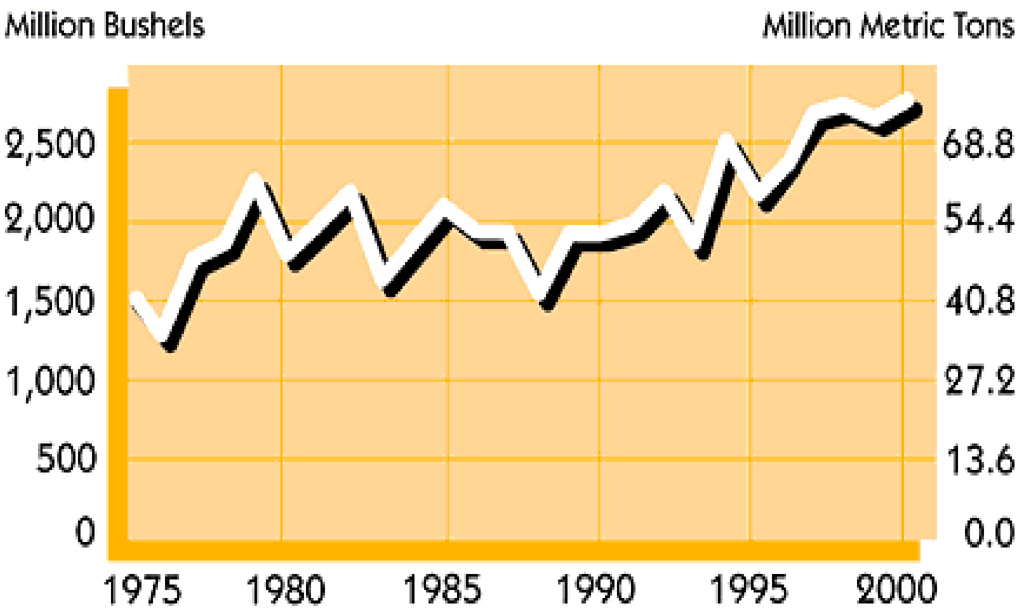
In a recent article published by Pro Farmer (an agricultural newsletter), editors asserted that research at Monsanto Centers of Excellence showed that, on average, no-till soybeans grown in narrow rows add $16 per acre more to a grower's bottom line than conventional soybeans grown in wide rows. Furthermore, "Seeding soybeans in no-till, or in a conservation-tillage system with a spring burn-down program following limited fall tillage, saves time and money at planting, and yields are at least as good as conventional soybeans in wide rows.” On a 1,000-acre farm no-till can save as much as 450 hours of time and 3,500 gallons of diesel fuel each year. That's eleven 40-hour weeks in time savings and $4,000 less for diesel at $1.15 per gallon, notes Rahe (Southeast Farm Press, 2000). This seems quite promising! It is therefore not surprising that proponents of these new technologies argue that the availability of postemergent herbicides (eg. Roundup Ready) that can be applied during the growing season has facilitated the use of reduce till (including no-till). In fact it is believed that this trend is likely to intensify because it may allow for the use of a more effective and less costly weed control regime than the traditional methods (Carpenter and Gianessi, 1999). Undoubtedly this synergy may be established if one can easily control weeds even after crop growth without tilling the soil.

It is also important to note that the development of transgenic crops with superior input traits has also had a major impact on the production of traditional crops, especially in the market for crop protection products (agrochemical markets). For example, in 2000 about 68% of U.S. soybean area was planted with herbicide tolerant crops (including Roundup Ready soybean) which was up by about 16% compared to the acreage in 1999. This effectively contributed to the reduction in the sale of conventional herbicides.

Prior to the introduction of Roundup Ready soybeans, selective products based on imidazolinone and sulfonylurea chemistry (postemergent gramicides) dominated the US herbicide market. However, since its introduction, RR soybeans weed control system has steadily gained market share, comprising about 60% of US plantings in the period 2000-2002. One therefore wonders, what impact the adoption of this cost-saving soybean variety (RR) will have on the soybean market in the United States and ultimately the world market.

A brief consideration of the U.S soybean industry shows the production of U.S. soybeans growing at a considerable rate and a corresponding increase in the U.S. supply and export of soybeans. USDA estimates from figure 1 below, shows that compared to the 1975 level of production (40.8 million metric tons), the soybean industry has seen a tremendous growth in its production, to more than 68 million metric tons in 2000.

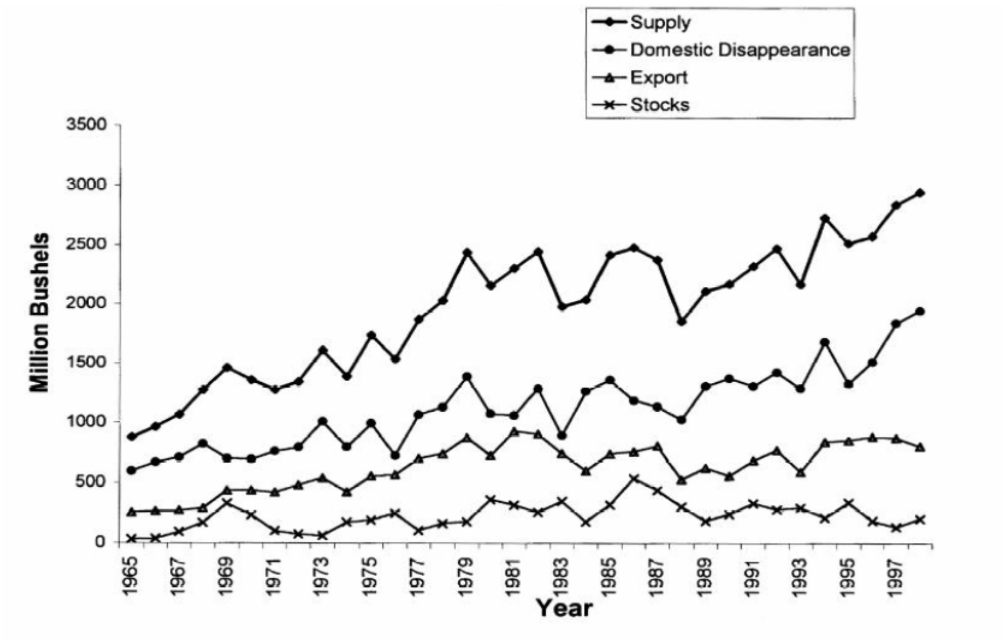
Figure 1. U.S. Soybean Production 1975-2000



Source: USDA

Even though the U.S production fluctuated around 40 million metric tons between the early eighties and nineties, productivity picked up in the mid to late nineties causing the supply of soybeans on the U.S market to rise to about 73 million metric tons in 1998.

Figure 2. U.S. Soybean Supply and Disappearance, 1965-1998



Source: USDA

Information from figure 2 further shows that in the same year (1998) about 28% of the total supply of soybeans was exported with exports reaching 800 million bushels while the remaining 72% (2.1 billion bushels) was used for domestic consumption. It is further illustrated in figure 2 that the supply of soybeans in 1998 was about three times higher than it was in 1965 (about 0.876 billion bushels). This upward trend in soybean supply has been attributed to a number of reasons, including the increase in soybean acreage (from 34.4 million to 69.1 million harvested acres according to the USDA data source) which surpassed that of wheat in 1998. It may also be due to the availability of the improved soybean varieties, including Roundup Ready soybean, vis-à-vis the availability of better farming practices. Figure 2 also shows that as export demand has risen, the domestic use of soybeans has also increased. This shows the growing demand for U.S. soybeans by the global economy. With new technologies and better farming practices, the U.S. briefly became the largest producer of soybeans in the world (at least in 1998), producing about 47.5% (2.7 billion bushels) of the world's soybeans production. This exceeded the production from rival producers such as Brazil, Argentina, and China with 19.6%, 12%, and 8.7% of the world's soybean production respectively. In 1998, the U.S. was also the largest user of soybeans in the world with 1.8 billion bushels used domestically, which was about 32% of the world's soybeans disappearance. U.S. exports were about 56% of the world's total exports in 1998 while Brazil exported 23% and Argentina exported 8% of the world's total soybean exports. Appendix C shows that even though there was a slight dip in U.S. soybean production during the period 2002-2003, the current numbers reported by USDA for soybean production in 2004 show that there was a sharp increase in production from a low of 2.45 billion bushels in 2003 to 3.14 billion bushels. This was coupled with a further increase in soybean planted acreage to 75.1 million acres. With the current trend in demand for U.S. soybeans, and the potential for exports, there has been a lot of effort put into sustaining the production of soybean in the U.S. Researchers have thus sought to promote new seed varieties including RR soybeans, in addition to other farming techniques in order to meet the ever-growing demand for U.S. soybeans.

Recently, there have been a lot of studies comparing conservation tillage and conventional tillage. Previous studies comparing the profitability of alternative tillage systems include Henderson and Stonehouse (1998). While several studies have developed models analyzing an individual's decision to adopt a new technology, there is relatively little work done on examining the factors that influence the decision to adopt more than one interrelated technologies. Thus far, only a few, for example Khanna (2001), have considered the simultaneous adoption of two technologies, soil testing and variable rate technology

(VRT). Other researchers have considered the adoption of complete packages such as conservation tillage (Rahm and Huffman) or site-specific farming (Daberkow and McBride).

Furthermore, unlike Gotsch and Wohlgenant (2001), most of the existing papers have ignored the market effects of the adoption of farming technologies on agricultural markets. This is crucial for the current study of the simultaneous adoption of Roundup Ready soybean and no-till technology, which has been promoted as the complementary farming technology of choice by Monsanto Corporation.

1.2 Objectives of the Study

One of the main objectives of this study is to reconcile the claims made by Monsanto and other researchers (agronomists) with data to ascertain whether farmers are adopting no-till and RR soybean technologies simultaneously or not. Therefore in this study, we will seek to verify whether the availability and use of Roundup Ready soybeans is encouraging farmers to adopt no-till practices for soybean production. This is because it has been argued that the availability of herbicide-tolerant soybeans may affect the decision to adopt no-till, while the use of no-till on the other hand, might also impact the decision to adopt herbicide-tolerant seeds (Price et al., 2003).

The current research is also aimed at identifying and analyzing the factors influencing the concurrent adoption of no-till and RR soybeans as well as those that affect the single adoption of the individual technologies and the extent of the adoption. This is necessary because even though some farmers will adopt the two technologies at the same time, others might adopt pieces of the package rather than the whole in a sequential or stepwise way. Feder et al. (1985) argues that while the components of a technological package may complement each other, some of them might be adopted independently. Our treatment of the model in this manner will therefore help us fully understand the factors that explain the adoption process.

Another objective of the current study is to investigate whether the two technologies are complementary to each other. The null hypothesis here is that there is no complementarity between the two technologies. Although this paper cannot fully prove the presence or absence of complementarity, by appealing to the theory of supermodularity, it proposes a simple empirical test to establish and verify a necessary condition for the presence of synergy between the adoption of no-till and RR soybean technologies.

In a bid to answer the empirical questions on technology adoption above, a feasible generalized least squares (FGLS) model and a Tobit model are used to identify the factors influencing single adoption, while a simultaneous two-equation econometric model is developed and used to analyze the potential simultaneity between the two technologies. This helps reveal the factors that are most important in explaining the simultaneous adoption of no-till and RR soybeans and to test the proposed hypothesis of simultaneity.

A final goal of the dissertation is to consider the market impact of the adoption of the new technology (i.e. measure marshallian surpluses). The economic impact of the adoption of RR soybeans discussed here includes a combination of changes in the cost of production and the changes in the price of soybeans due to the introduction of RR soybean varieties, causing an outward shift of the supply curve. The changes in cost and price per unit area are estimated using farm level survey data and then aggregated using available data on the area planted with the new varieties. The welfare effects of an induced supply shift (assuming parallel or pivotal shifts) resulting from the technological change is analyzed to see how it differs for producers, consumers, both in the adopting country and in the rest of the world (ROW). The market considered here is therefore divided into two sectors; one made up of adopters of Roundup Ready technology, the USA and the other non-adopters of RR soybeans, ROW.

A theoretical model is developed for Roundup Ready soybeans with the United States (US) as a large producer country and all other countries will be aggregated as the rest of the world (ROW). The analysis will then proceed with the determination of producer and consumer surpluses for the various groups considered as the supply curve shifts outward with the adoption of the technology.

1.3 Dissertation Overview

The current study has two parts, the first part deals with the individual and simultaneous adoption of no-till and RR technology while the second half investigates the market impact of the adoption of the new technology. The rest of the paper continues with a literature review of the most relevant papers on the adoption of agricultural technologies in chapter 2 followed by a theoretical model of the simultaneous adoption of no-till and RR soybean technology in Chapter 3. Chapter 4 of the current study provides information on the data used for our empirical analysis and a summary of the survey data results. In chapter 5, I discuss some of the econometric issues encountered in this study, while chapters 6 and 7 provide information on the empirical models that were estimated in order to understand the factors driving the adoption of the technologies and the presence of complementarity. Chapter 8 presents and discusses the empirical results. In chapter 9, I discuss the market impact of the adoption of RR technology, provide the necessary equations needed to calculate economic surpluses and discuss the data used for the analysis. Chapter 10 of the thesis discusses the welfare impacts following the adoption of the new technology. The welfare benefits to producers and consumers in the United States and the rest of the world is thus presented. Chapter 11 concludes the study with a summary of the findings, the difficulties encountered, and the inadequacies or limitations of the current study.

Chapter 2

2.1 LITERATURE REVIEW

For decades now there has been a growing concern about the impact of agriculture on the environment. While food production remains essential for our existence, the processes used to provide food might generate negative externalities (such as sedimentation, surface and groundwater contamination) as well as possibly destroy the soil structure. Proponents of sustainable agriculture have suggested a number of types of cropping systems and management schemes such as using forages in a cropping sequence with grains to reduce soil erosion, reduce tillage, and no-till cropping, which they argue are more environmentally friendly and could yield greater or equal productivity when adopted. This section concentrates on a review of selected literature related to technological adoption in the agricultural sector.

Since the seminal work of Grilliches (1957) a vast span of literature has evolved aimed at explaining the factors that influence the adoption of agricultural technologies. In his research on hybrid corn, Grilliches (1957) identified profitability as the most important determinant of adoption. Rogers (1983), however, argued that profitability is only one factor of five attributes of technology. He claims that profitability can be considered as a relative advantage while other important attributes of innovation include: compatibility, complexity, triability, and observability.

Researchers since Grilliches have employed economic decision models to derive theoretical results predicting the qualitative effect of factors (such as risk attitudes, farm size, liquidity constraints etc.) on the decision to adopt a new technology. However, most of the past studies of technology adoption, have focused on either a single new technology (e.g.

adoption of an improved seed variety or irrigation system as in Caswell and Zilberman, 1985) or on a set of technologies considered as a single unit (e.g. integrated pest management notably, Harper et al., 1990; McNamara, Wetzstein and Douce, 1991).

A number of theoretical studies of the adoption behavior of individual farmers have considered risk and uncertainty, arguing that innovations may entail subjective risks (that yield is more uncertain with an unfamiliar technology) and usually objective risks (due to weather changes, susceptibility to pests and diseases etc.), as in Feder et al. (1985). However, of the many papers that have focused on the role of risk and uncertainty, very few have provided rigorous empirical investigation to verify their claims or hypothesis. These exceptions include studies conducted by Byerlee and de Polanco (1986) and Marra and Carlson (1987).

Byerlee and de Polanco (1986) argue in their paper that research and extension programs should take cognizance of the fact that farmers adopt improved technological components in a stepwise manner. They use on-farm experimental survey data to provide evidence that farmers in a developing country such as Mexico adopted improved varieties, fertilizer and herbicide for barley in a stepwise process, in spite of the significant interaction between the components of the technological package. Hypothesizing that the time of initiation of adoption and the rate of adoption depend on profitability, riskiness, divisibility, complexity, availability and the interaction between components of an innovation, they argue that their results, like those of Rogers (1983), reveal that profitability and riskiness affect the adoption of each innovation most.

It has also been argued that farm size has an effect on the adoption of agricultural technologies (Feder 1980); Marra and Carlson (1987) provide evidence in support of this hypothesis. Marra and Carlson (1987) used farm-level data on the adoption of double-cropped wheat/soybeans to empirically provide evidence to support the idea that the combined effects of decreasing absolute risk aversion and covariance of returns are likely to be limiting factors in the farm size-adoption relationship. This further substantiates the fact that larger farms are more likely to adopt new technologies than smaller farms.

Feder (1980), on the other hand, considered the effect of farm size on land allocation. He assumes risk aversion and utilizes a constant-returns-to-scale version of the stochastic production function $y=f(x)+g(x)\varepsilon$ to show that the share of land allocated for the cultivation of a modern crop as opposed to a traditional crop depends on the relationship between relative risk aversion and income. In his model it is assumed that the cultivation of new crop varieties does not require any fixed initial cost, but is associated with higher uncertainties compared to traditional crops. It was realized that fertilizer use per acre (for the new crop) was independent of the degree of risk aversion, uncertainty and farm size when credit constraints are non-binding.

In another study, Just and Zilberman (1983) extended the model in Feder (1980) to consider all inputs using the same production function. They argued that the intensity of use of modern inputs depends on whether it is risk reducing or risk increasing and on whether relative risk aversion is increasing or decreasing. Their findings revealed that the correlation of output under alternative technologies played an important role in determining adoption rates. The argument was advanced that if the correlation of output under old and new technologies is low or negative, or if the modern technology is relatively more riskier, then larger farms will devote more land in absolute terms but less in proportionate terms to the new technology than will small farms if relative risk aversion is increasing and absolute risk aversion is decreasing with the farmer's wealth.

Feder (1982) presents a model that analyzes farm level decisions made regarding the choice of interrelated innovations. The innovations here were distinguished by their returns to scale and were assumed be adopted individually. The paper demonstrates that under conditions of uncertainty or binding credit constraints, the concept of complementarity of technologies might be misleading. It was emphasized that in examining the interrelationship between the different components of an innovation one cannot ignore endogenous constraints such as risk aversion and credit scarcity in order to establish that complementarity exists. The author argued that yield complementarity is not necessarily a good indicator of complementarity. Regarding the adoption of divisible and lumpy components of a technological package, the paper showed that variable-input subsidies could enhance the adoption of both. However, due to scarcity of credit, it was determined that subsidies might stimulate the adoption of scale-neutral innovations while discouraging the adoption of lumpy technologies, even when the two seem complementary to each other.

With regard to human capital, Wozniak (1984) developed a model of the decision to adopt interrelated technologies emphasizing the role of innovative ability as a measure of the economic incentive to be informed about innovations. The author hypothesizes that education, experience and the availability of information are measurable dimensions of innovative ability. By fitting univariate, conditional, and joint logistic models it was shown that innovative ability contributes significantly to explaining the adoption of new technologies but does not explain its diffusion. It was also concluded from the results that the diffusion of previously available innovations depends on the introduction and adoption of interrelated current innovations. The paper concludes by submitting that if an innovation is compatible with current technology it is more likely to be adopted than if it displaces it. Furthermore, the probability of using earlier innovations in the current period is higher if complementary current innovations are adopted.

Kling et al. (2001) argue that "even when conservation practices can raise a farmer's expected profit, he might be reluctant to adopt either because he is risk averse and (or) because adoption involves sunk investment and real options are present. If so, the farmer adopts only if the additional profit of a conservation practice overcomes a premium." In their paper, the authors proposed a method of directly estimating the financial incentives for adopting conservation tillage and differentiating between the expected payoff and the premium of adoption. They incorporated weather variation directly into the premium, and estimated it based on observed behavior using an “adoption model.” An econometric specification was then derived from the behavioral model (noting the innovation that allows recovery of the structural coefficients) followed by estimation using empirical data. Results generated from this work supported the fact that the adoption premium may play a significant role in farmer's adoption decisions (on average accounting for about 17% of their annual profits).

The paper by Kling et al. (2001) contributes to the adoption literature in two ways. First, it avails a new modeling strategy that allows for full recovery of the structural coefficients and the direct computation of premiums needed for adoption of a farming practice. Secondly, it calculates the subsidies that were needed to achieve any given level of conservation tillage adoption.

Economists have also used Bayesian models to explain aspects of technology adoption (O'mara, 1983; Jensen, 1982; Hiebert, 1974). However in explaining the sequential adoption of agricultural innovations, Dorfman (1996) and Leathers and Smale (1991) are of special interest as far as the adoption of multiple technologies is concerned. Leathers and Smale (1991) also presented a behavioral model, which explains the sequential adoption of components of a technology as a consequence of learning by adopting farmers. They demonstrated that in order to learn more about the entire technological package, a risk neutral farmer who is unconstrained in his expenditures might adopt a component of an innovation instead of the whole package in spite of the profitability associated with the adoption of the whole package.

Dorfman (1996) demonstrated how Gibbs sampling can be used to reduce the computational difficulty associated with applying the multinomial probit model to multivariate decision models. The author uses a multinomial probit model to model the adoption decisions of farmers facing multiple technologies, which he posits could be adopted in different combinations. Subsequently, he examines the farmer's adoption of improved irrigation and integrated pest management technologies as four possible relative choice decisions: adoption of neither, integrated pest management practice only, improved irrigation only, or both. The study proceeded with estimation in the Bayesian framework employing Gibbs sampling to estimate a multinomial probit model. The results of the research show that the adoption decisions are significantly influenced by off-farm labor supply.

Wu and Babcock (1998) expanded the work on the adoption of single technologies to the simultaneous estimation of the choice of soil nitrogen testing, rotation, and conservation tillage for corn farmers in the Central Nebraska Basins area. To estimate the joint adoption decisions of the conservation practices, they used a polychotomous-choice selectivity model to control for self-selection bias. From eight possible combinations of conservation tillage, rotation and soil testing, the authors designed eight conservation plans to evaluate the impact of alternative management plans on corn yields and nitrogen and phosphorus application rates. It was noted that farmers who followed the conservation plans increased their use of crop rotation and conservation tillage. This was used as evidence to support the fact that eliminating the incentives to follow conservation compliance by decreasing federal subsidy levels will decrease the use of conservation practices. They also found that the adoption of conservation tillage was significantly affected by the physical characteristics of the site and farmer education.

The role of information in the adoption and diffusion process has been investigated extensively, however Marra et al. (2001) is notable among the few papers that have incorporated technology depreciation. In their article, Marra et al. (2001) conducted a study on the various sources of information and the quality of information regarding the profitability of biotech cotton (Bt cotton) and how relevant such information is to farmers in the adoption process. They develop an adoption decision model that incorporates the role of information quality as well as the effect of the depreciation in current technology. The authors identified factors that determine the early adoption of Bt cotton technology and further found evidence supporting the fact that all three factors (the source, quality of information and depreciation of technology) are significant determinants of the adoption of Bt cotton.

In a recent paper, Khanna (2001) analyzed farmers' sequential decision to adopt two site-specific technologies (soil testing and variable rate technology) and the impact of adoption on nitrogen productivity. The paper discusses some factors that motivate the adoption of the two technologies and their effect on the productivity of input. She found that in four Midwestern states, the location of the farm was important in the decision to adopt soil testing, however human capital, farm size and innovativeness of farmers had a significant impact on the adoption of variable rate technology. The author applies a double selectivity model to correct for sample selection bias, and concludes that there were significant gains in nitrogen productivity for farms whose soil qualities were above average when the two technologies were adopted.

Kalaitzandonakes and Suntornpithug (2003) observed that "previous adoption studies have considered the uptake of agro biotechnologies one at a time, that is, separately from the adoption of other related agronomic practices." The authors argue that this approach is likely to be narrow and might limit one's understanding of the factors that drive the adoption of such technologies and what their impacts might be.

In their model, it is argued that producers' behavior is characterized by multiple simultaneous and interdependent decisions on the adoption of three different cotton biotechnologies (Bollgard Cotton, Roundup Ready Cotton and Stacked Bollgard/Roundup Ready Cotton) with reduced tillage and irrigation technologies in US cotton production. The model used also allows for partial adoption of one or more of these technologies as a way of optimizing their use through learning by doing. The adoption equations were estimated using Generalized Method of Moments (GMM), three stage least squares (3SLS) and full information maximum likelihood (FIML) procedures. These models produced similar results. It was concluded that reduced tillage practices encouraged the adoption of RR and Stacked Bollgard/Roundup Ready Cotton. Interestingly, their results confirmed the arguments made in a previous study by Marra et al. (2001) that depreciation and diminished effectiveness of conventional pest control practices is the most significant factor contributing to the rapid adoption and diffusion of Bollgard (BG) technologies.

Noticeable amongst the papers that have related the adoption of innovations to the corresponding welfare effects on consumers and producers, Moschini et al. (2000) developed a three-region world model for the soybean complex and evaluated the welfare effects of the adoption of Round-up Ready soybeans. The model takes into account the incentives for farmers to adopt RR soybean. It also assumes that the industry supplying the innovation faces imperfect competition while the industry that purchases the innovated intermediate inputs (i.e. the farm sector) is competitive. The authors argue that innovators' exploitation of institutionalized market power (monopoly rights) has considerable implications for the evaluation of the welfare effect of agricultural innovations. Their results suggest that the United States (the innovating country) gains a larger share of the welfare benefits of the RR innovation. However spillover to foreign competitors tends to erode the competitive ability of US producers. It was concluded that consumers in every region gain from the adoption of RR soybeans.

Further work by Gotsch and Wohlgenant (2001) demonstrated that the welfare effects of a regional technical change (such as improving the cocoa plant genetically against pathogens) differ for consumers, producers and the Rest of the World (ROW). It was argued that the magnitude of producer and total benefits depend on the type of supply shift assumed (i.e. parallel or pivotal shift). The model used considers the market for cocoa, with Malaysia as a large country producer and all other countries as an aggregate. One significant aspect of the model proposed by Gotsch and Wohlgenant (2001) is that they incorporate the dynamics of perennial crops into their analysis and show that Malaysian producers gained significant economic surpluses, while consumers' gains in the Rest of the World (ROW) were offset by producers' losses in the ROW.

In spite of the sizeable amount of work done on the adoption of agricultural technologies, the market effects of the concurrent adoption of two or more complementary technologies has not been fully exhausted, which motivates the current study.

Chapter 3

3.1 A Theoretical Model for the Simultaneous Adoption of No-till and RR Soybean

In this model it is assumed that households potentially participate in multiple farm activities such that in adopting agricultural technologies, they could possibly engage in both old and new farming practices for crop production. The new farming technologies considered here are: no-till farming and roundup ready seed technology.

Assume that the soybean market is a competitive market,

Let

n = no-till technology,

t = tillage technology,

R = roundup ready soybean seed,

S = traditional soybeans,

P = market price of soybeans,

W^n = per unit cost or rental price of no-till investment resource,

W^t = per unit cost or rental price of resources investment into tillage cultivation,

W^s = per unit cost of traditional soybean seeds,

W^R = per unit cost of roundup ready soybean seeds,

R^t = acres of land under tillage, used for cultivating RR soybeans,

R^n = acres of land under no-till technology, used for cultivating RR soybeans,

S^t = acres of land under tillage, used for cultivating traditional soybeans,

S^n = acres of land under no-till used for cultivating traditional soybeans,

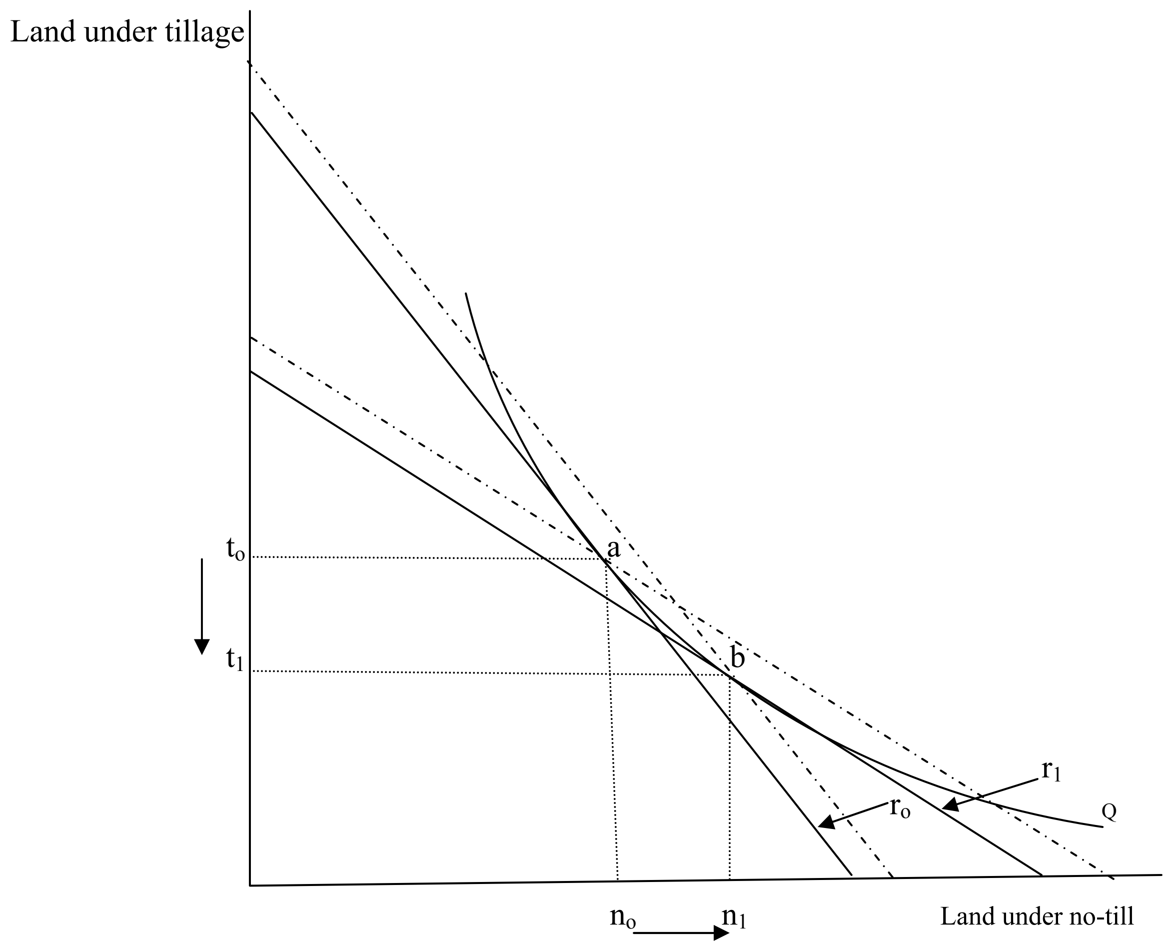
$\bar{L}$ = the total acreage used to produce soybeans,

L^n = the portion of total acreage used for no-till soybean production,

L^t = the portion of total acreage used for soybean production under tillage.

3.1.1 Conceptual Framework of the Model

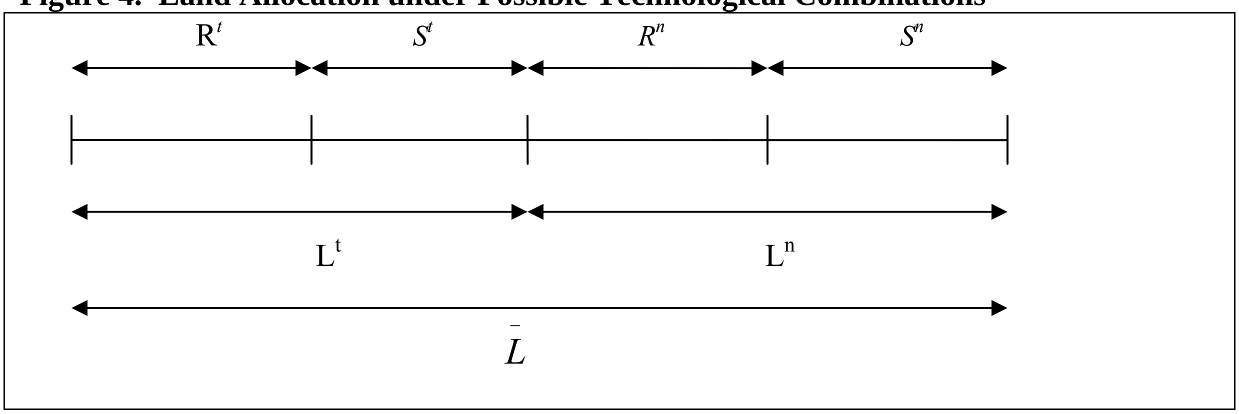
Figure 3: 'No-till – Tillage' Input Substitution



This model is constructed under the assumption that input substitution (in the form of the diversification of land usage) is possible because more than two technological packages are available to the farmer in this production process. Referring to figure 3 above, this possibility can easily be illustrated graphically where Q represents a particular quantity of soybean output cultivated under a given state of seed technology (i.e., traditional or roundup ready). Assume further that farmers have the option to plant soybean under tillage and no-till technology with different portions of land allocated for tillage and no-till used as inputs in each technological combination.

When the input price of tillage technology relative to that of no-till is given by r_o, cost minimizing producers will use the input combination t_o and n_o at point *a* to produce the soybean output Q. However, if the price of no-till falls relative to that of tillage (i.e., from r_o to r_1), producers will substitute land under no-till for that under tillage to minimize the cost of producing the same quantity of soybean output Q at point *b* (using input amounts t_1 and n_1, thus indicating the corresponding increase in acreage for the cheaper technology from n_o to n_1.

Figure 4. Land Allocation under Possible Technological Combinations



As assumed earlier, farmers allocate their available investment resources (i.e. land $\bar{L}$ and soybean seeds) between the two farming practices no-till (new technology) and tillage (conventional technology). Therefore this model as depicted in figure 4 is constructed such that different acres of land are apportioned between the two technologies that are used for planting traditional and RR soybeans. However, households are assumed to be faced with an investment constraint such that the sum of the farmer's investment resources cannot exceed the farmer's total endowments.

Subsequently, from the assumptions made above, the profit generated by farmers from engaging in the different farming activities can generally be represented as:

$$\phi(R^t, L^t, L^n, R^n, S^t, S^n; w^R, w^s, w^n, w^t) = P[f^{tR}(R^t) + f^{ts}(S^t) + f^{nR}(R^n) + f^{ns}(S^n)]$$
$$- w^R(R^t + R^n) - w^s(S^t + S^n) - w^t L^t - w^n L^n. \qquad (1)$$

Where the functions $f^{ij}(.)$ are concave production functions that are twice continuously differentiable and f'(.)>0, f''<0 hold true. Furthermore, $f^{ij}(.)$ defines a production function for soybean cultivated under a given farming practice and seed type.

Assuming that the resource constraint is binding, the farmer's problem can be represented as a maximization of his total profits subject to the resource constraint;

This implies,

$$Max\, \phi(R^t, L^t, L^n, R^n, S^t, S^n; w^R, w^s, w^n, w^t) = P[f^{tR}(R^t) + f^{ts}(S^t) + f^{nR}(R^n) + f^{ns}(S^n)]$$
$$- w^R(R^t + R^n) - w^s(S^t + S^n) - w^t L^t - w^n L^n, \qquad (2)$$

s.t.

$$L^n + L^t = \bar{L}, \qquad (3)$$

$$S^t = L^t - R^t, \qquad (4)$$

$$S^n = L^n - R^n. \qquad (5)$$

Equation (2) can be expressed and solved as the unconstrained maximization problem below after imposing the constraints:

$$\max_{R^n, R^t, L^t} \ \phi(.) = P[f^{tR}(R^t) + f^{ts}(L^t - R^t) + f^{nR}(R^n) + f^{ns}(\bar{L} - L^t - R^n)$$
$$- w^R(R^t + R^n) - w^s(\bar{L} - R^t - R^n) - w^t L^t - w^n(\bar{L} - L^t). \tag{6}$$

This yields the following first order conditions:

$$\frac{\partial \phi(.)}{\partial R^n} = P[f^{nR'}(R^n)^* - f^{nS'}(\bar{L} - L^t - R^n)^*] - w^R + w^S = 0, \tag{7}$$

$$\frac{\partial \phi(.)}{\partial R^t} = P[f^{tR'}(R^t)^* - f^{tS'}(L^t - R^t)^*] - w^R + w^S = 0, \tag{8}$$

$$\frac{\partial \phi(.)}{\partial L^t} = P[f^{tS'}(L^t - R^t)^* - f^{nS'}(\bar{L} - L^t - R^n)^*] - w^t + w^n = 0, \tag{9}$$

where $\phi(.) = \phi(R^t, L^t, L^n, R^n, S^t, S^n; w^R, w^s, w^n, w^t)$.

Interpreting these first order conditions, we can generally infer that farmers will allocate land for the adoption of agricultural technologies as long as the marginal benefit (MB) of the utilization of land for a given technology exceeds the marginal costs associated with it, until the point where the marginal benefit becomes just equal to the marginal cost of apportioning an extra piece of land to the technology. Furthermore, it can be seen that as the farmer tries to maximize his profits in allocating land for a given technology, he gains by an increase in the marginal productivity of some technological combination at the expense of the productivity of another technology used on the remaining portion of the land. This is reflected in the marginal cost he incurs from the technology adoption process. The marginal benefit is therefore derived from the difference between the marginal product of using one technology as opposed to the use of another, while the marginal cost is basically the difference between the input costs of the technologies in question. We can easily interpret the first order conditions to show that the allocation of resources by diverting them from one technology to another results in a trade-off (opportunity cost) in the value of marginal products of technologies given up.

It follows from equation (7) that, for a fixed amount of land allocated for no-till cultivation (L^n), a marginal increase in Roundup Ready soybean acreage under no-till technology (R^n), requires a reduction in the amount of land used for cultivating traditional soybeans (S^n). Therefore, by utilizing Roundup Ready soybeans and cutting back traditional soybean acreage, the farmer incurs a marginal cost of w^R due to the use of roundup ready seed input but reduces his overall marginal cost by an amount equal to w^s (the input cost of traditional soybeans) since it requires the loss of an equal amount of land used for traditional soybeans under no-till technology.

Equation (8) and (9) also follow the same line of thought. In (8), holding the total acreage under tillage (L^t) constant, an increase in the tilled acreages for roundup ready (R^t), results in the loss of some portion of land available for planting traditional soybeans (S^t) hence the deduction of the value of marginal product of land under tillage and traditional soybean cultivation. As a result of the inputs used, the farmer's marginal cost increases by w^R (incurred from the adoption and subsequent use of Roundup Ready soybeans) while it is reduced by a per unit cost of w^s (due to the reduction of the use of traditional soybeans).

Equation (9) on the other hand indicates that holding the total roundup ready acreage constant (i.e. tilled, R^t and no-till acreages, R^n), farmers can optimize the acreage of land under tillage L^t, at a unit cost of ($w^t - w^n$), which is positive. Subsequently, for a fixed R^t and R^n, an increase in L^t will result in a gain of more acreage used for traditional soybeans (S^t) and a loss of land available for planting traditional soybeans under no-till technology (S^n). This increases the per unit cost of operation by an amount equal to the cost of the purchase of inputs needed for traditional cultivation w^t but decreases the marginal cost by w^n, the cost of the utilizing no-till technology inputs. This is due to the fact that the changes in L^t holding R^t and R^n constant can only result from the loss of land under S^n, equal to the amount of change in L^t; i.e., $\Delta L^t = -\Delta S^n$.

The first order conditions above therefore represent the general behavior of a profit maximizing firm. It is required that farmers use inputs up to the point where the value of marginal product of the input or technology is equal to the marginal cost associated with the use of that input or technology. As indicated earlier, an examination of the first two first order conditions, confirms that for a change in acreage used for roundup ready, the difference between the value of marginal product under the new technologies (no-till and Roundup Ready) and the old technologies generally do not disappear to zero but is actually equal to the difference between the unit cost of the seed inputs for Roundup Ready and traditional soybeans. The difference only vanishes when the marginal value products of the technological combinations in question become equal.

Therefore it can be inferred that for a farmer to engage in the conservation tillage program (the new technology), the value of marginal product under the new technology should exceed the value of marginal product under the old technology by an amount at least equal to the excess over the unit price paid for Roundup Ready seed and traditional soybean seed input. This must be true in this case since it can be argued that even if the price of seed inputs were the same for Roundup Ready and traditional soybeans, the presence of technology fees on roundup ready if prohibitively high, may cause the price of adopting the technology to be relatively higher.

Equation (9) also follows the same argument. That is, for a change in the acreage under tillage, the productivity of land under no-till should exceed that under tillage at least by an amount equal to the difference between the rental prices for no-till inputs and tillage technology inputs.

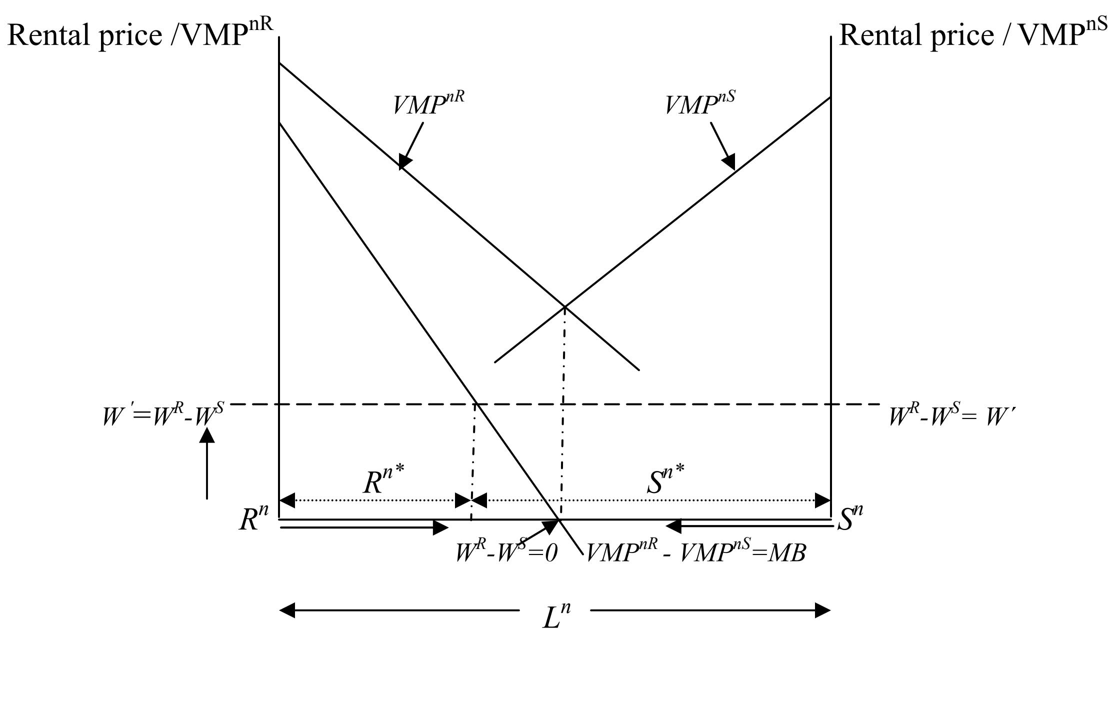
3.2 A Graphical Representation of the First Order Conditions

In figure 5 below, a graphical representation of the first order conditions discussed earlier is shown. The graphs show how the optimal acreages are determined or allocated as the farmer switches from one technology to another depending on the marginal benefit he derives from every unit of land he reallocates.

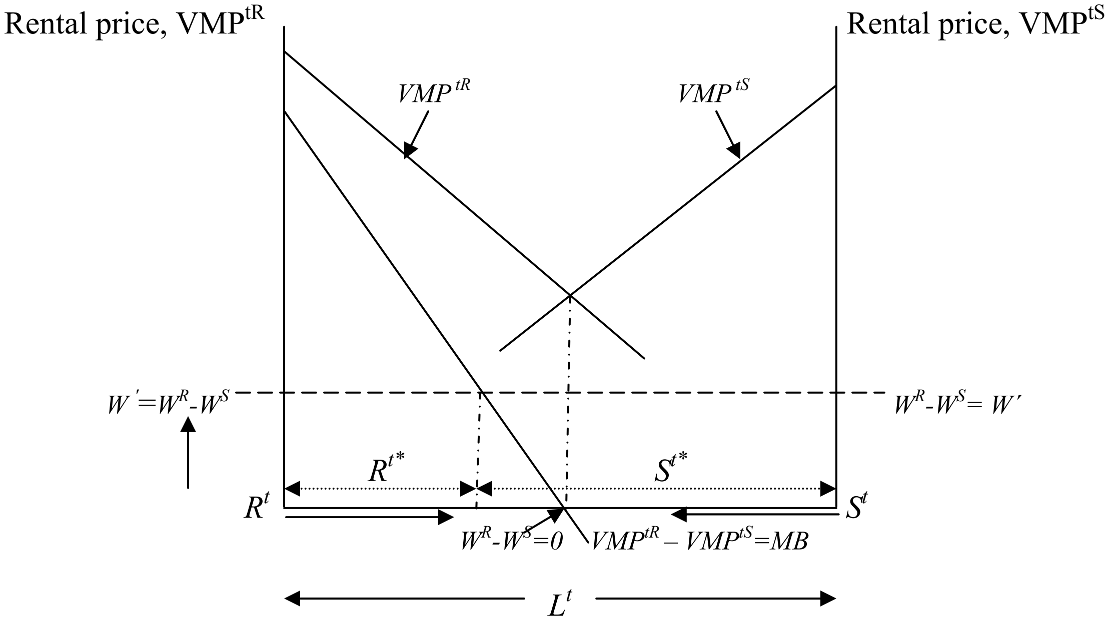
The aim here is to predict intuitively how a change in input prices would impact the allocation of land resources between the new and the old technologies (i.e. till or no-till *vis-a -vie* Roundup Ready or traditional soybeans). Subsequently, it is hoped that this simple graphical methodology will provide some valuable intuition for analyzing the comparative statics results that will be derived later on in this dissertation.

Figure 5: A Graphical Representation of the First Order Conditions Showing The Effect of Soybean Input Price Changes on Land Allocation

a)

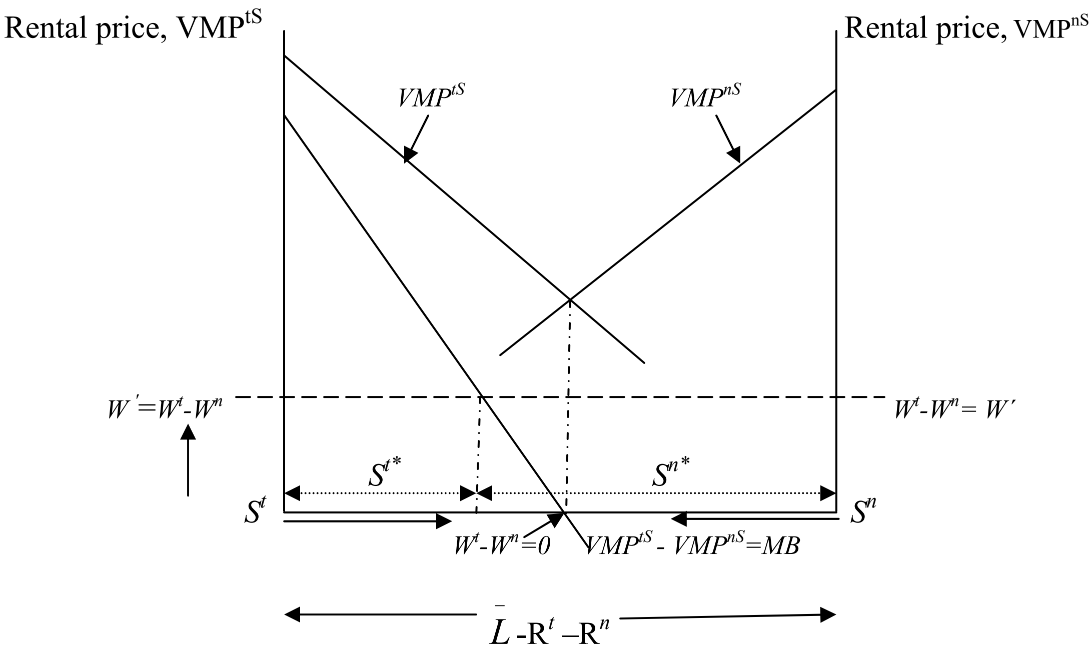


b)



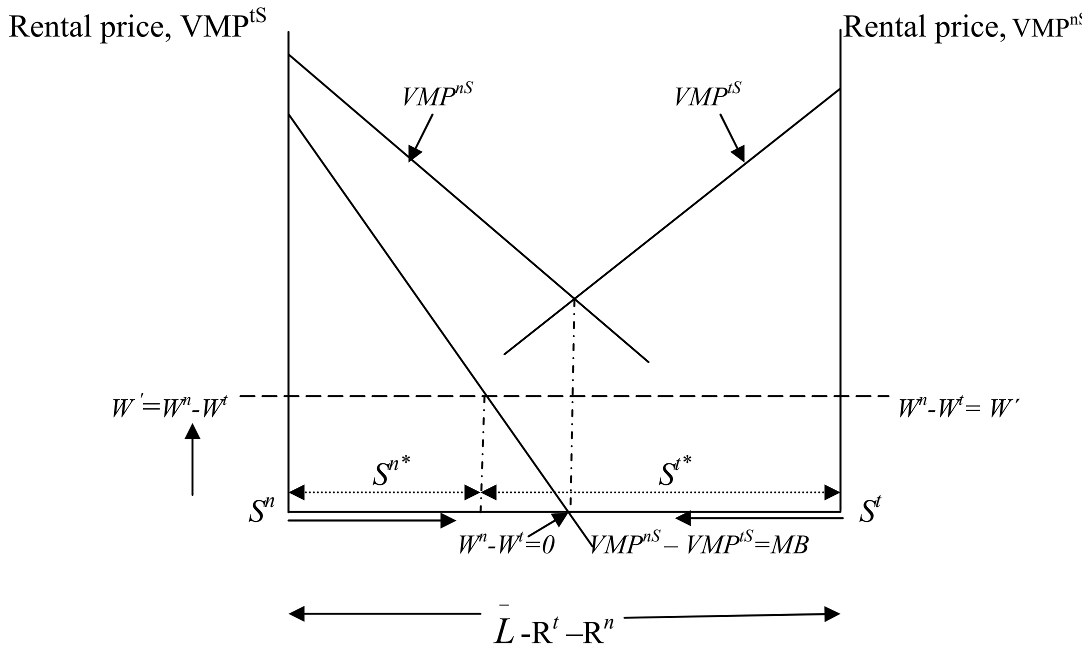
Rental price, VMP^tR
Rental price, VMP^tS
VMP^tR
VMP^tS
W′=W^R-W^S
W^R-W^S= W′
R^t*
S^t*
R^t
S^t
W^R-W^S=0
VMP^tR – VMP^tS=MB
L^t

c)



Rental price, VMP^tS
Rental price, VMP^nS
VMP^tS
VMP^nS
W′=W^t-W^n
W^t-W^n= W′
S^t*
S^n*
S^t
S^n
W^t-W^n=0
VMP^tS - VMP^nS=MB
L̄ -R^t –R^n

d)



Where,

VMP^{nR} is the value of marginal product of land used for planting no-till roundup ready soybeans.

VMP^{nS} is the value of marginal product of land used for planting no-till traditional soybeans.

VMP^{tR} is the value of marginal product of land used for planting roundup ready under tillage.

VMP^{ts} is the value of marginal product of land used for planting traditional soybeans using traditional cultivation practices.

The diagrams in figure 5 above present a plot of the value of marginal product and the marginal cost of a unit of inputs (on the vertical axis) against the amount of land available for planting soybeans (on the horizontal axis) for a given technology. As indicated earlier, VMP is the value of marginal product and the point at which the two value of marginal product curves intersect indicates the point where the difference between the value of marginal product vanishes to zero (the opportunity cost of the two technologies become equal). Importantly, this is the point at which the benefit of adopting one technology as opposed to another is non-existent thus, MB=0. Consequently, it can be interpreted as the point where the cost of inputs for the new technology is equal to that of the old technology. It is also assumed here that there are diminishing marginal returns to R^t, R^n, and L^t. This is because of the scarcity of land that is suitable for the production of soybeans. Therefore, following this assumption, the VMP curves have been shown as being downward sloping.

Figure 5a represents equation (7) in the first order conditions. In this panel, the VMP for R^n slopes from left to right and that for S^n also decreases from right to left. Even though these curves intersect at the point where W^R-W^S=0 (a point at which $VMP^{nR} = VMP^{nS}$ resulting in the optimum R^n and S^n), before this point is reached there is a significant positive difference in marginal products. The figure therefore shows the marginal benefit and the associated marginal cost of switching from Roundup Ready to traditional soybeans and vice versa. It is possible to derive from the graph some interesting comparative statics results. Assuming that there is an increase in the price of Roundup Ready soybean seeds (i.e. w^R increases), this causes the difference (W^R-W^S), to rise to W'. At this point a new optimal amount of land R^{n*} and S^{n*} are generated for the acreages allocated for the cultivation of no-till Roundup Ready and traditional soybeans respectively. In this case, it is seen that as

Roundup Ready soybean input cost rises, profit maximizing farmers will cut back on the amount of land allocated to no-till Roundup Ready (R^n) while the acreage used for no-till traditional soybean S^n is increased by an equal and offsetting amount of land (i.e. ΔR^n=-ΔS^n). On the contrary, for an increase in W^S, it can be seen that the amount of land used for Roundup Ready under no-till (R^n) increases as opposed to that used for planting traditional soybeans S^n. Here, too, the changes in acreages offset each other. This is because the opportunity cost of using no-till land for cultivating Roundup Ready soybeans instead of the traditional soybeans decreases. However, it is seen from our analysis that in spite of the impact that the input price change has on the no-till acreages used for Roundup Ready and traditional soybean, the total acreage under tillage L^t is not affected by the changes that occur within L^n.

On the contrary, if the marginal benefit of an extra unit of land under no-till exceeds that under tillage, a profit maximizing farmer will reduce the amount of land used in traditional soybean cultivation under no-till in order to increase the amount of land used for roundup ready cultivated under no-till technology. Furthermore, the farmer may find the optimal allocation of land at a point beyond where W^R-W^S=0 and MB=0, (i.e. a point beyond which more land is optimally allocated to no-till technology in this case), if the cost savings of adopting no-till and Roundup Ready technology in terms of the time spent farming and herbicide cost exceed the marginal cost of purchasing Roundup Ready seeds including the technology fees.

Equation (8) in the FOCs can be represented graphically as figure 5b. Here I plot the value of marginal product of land used for planting Roundup Ready and traditional soybeans under tillage, against the acreage of land that is tilled. The portion of land R^t is read from left to right and S^t is read from right to left. Here again, this graph allows us to investigate the incentives that encourages farmers to switch from traditional soybean seed technology to Roundup Ready seed technology under tillage cultivation. Analyzing the input price changes in this graph, it is realized that for an increase in W^R and a subsequent increase in (W^R- W^s), a profit maximizing farmer will reduce the amount of land in R^t until the optimal level R^{t*} is attained. This results in an increase in S^t by the amount of the decrease in R^t. Here again, while L^t remains unchanged, L^n is also not influenced by the changes in R^t and S^t. However, the difference in the marginal value products of R^t and S^t increases invariably increasing the opportunity cost of given up a portion of R^t for S^t. Conversely, when W^S increases R^t increases and S^t falls by an equal and offsetting amount (i.e. ΔR^t=-ΔS^t) and the opportunity cost of the trade-off between the gains from an extra unit of land used for planting traditional soybeans S^t instead of the cultivation of R^t decreases. As in figure 5a, it can also be inferred that when the benefit of engaging in the use of Roundup Ready exceeds that of traditional technology the marginal benefit of shifting from traditional to Roundup Ready seed technology will be positive. In other words, if the cost savings from time and herbicides makes adopting Roundup Ready soybeans relatively cheaper than using traditional soybean, the marginal benefit of switching to the new technology will be positive.

Finally the analysis of equation (9) in the first order conditions can be reconciled with the graph in figure 5c and 5d assuming that the resource constraint is binding. The plot shows the value of marginal product of land plotted against the amount of tilled and no-till land used for the cultivation of traditional soybeans respectively. It thus shows how the farmer reconciles the marginal benefit of switching from traditional technology to no-till technology with the associated marginal cost.

Since this first order condition holds for $\frac{\partial \phi(.)}{\partial L^n}$ = - $\frac{\partial \phi(.)}{\partial L^t}$, assuming that the land resource constraint is binding, the graphical interpretation provides the intuition that, for an increase in no-till input price, the amount of land used for no-till is reduced (S^n falls) while that used for planting traditional soybeans under tillage S^t, increases. However, if no-till input price falls or tillage technology input price increases (the resultant marginal cost W^t- W^n, increases), therefore the amount of land used for no-till increases by the amount of decrease in the acreage of tilled land. Therefore, if the farmer perceives that the cost of switching from no-till to tillage is costly S^n will increase at the expense of S^t. This is obviously possible since the overall opportunity cost (in the form of the rental price of inputs, w^o=W^t- W^n) of switching land from tillage to no-till technology decreases as W^t increases. In this case it implies that farmers will have an incentive to switch from tillage technologies to the new technology if the difference between the value of marginal product of land under no-till and that under tillage is positive.

3.2.1 *Second Order Conditions and Comparative Statics*

The second order conditions are related to the following Hessian matrix:

$$H=\begin{bmatrix} \dfrac{\partial^2\phi(.)}{\partial(R^n)^2} & \dfrac{\partial^2\phi(.)}{\partial R^n R^t} & \dfrac{\partial^2\phi(.)}{\partial R^n L^t} \\ \\ \dfrac{\partial^2\phi(.)}{\partial R^t R^n} & \dfrac{\partial^2\phi(.)}{\partial(R^t)^2} & \dfrac{\partial^2\phi(.)}{\partial R^t L^t} \\ \\ \dfrac{\partial^2\phi(.)}{\partial L^t R^n} & \dfrac{\partial^2\phi(.)}{\partial L^t R^t} & \dfrac{\partial^2\phi(.)}{\partial(L^t)^2} \end{bmatrix}$$

H must be negative definite, which requires:

$|H_1|<0,\quad |H_2|>0,\quad |H_3|<0.$ The specific elements in the Hessian matrix above are:

$\phi(.)_{R^nR^n}=P[f^{nR''}+f^{nS''}]<0,$

$\phi(.)_{R^nR^t}=0,$

$\phi(.)_{R^nL^t}=Pf^{nS''},$

$\phi(.)_{R^tR^n}=0,$

$\phi(.)_{R^tR^t}=P[f^{tR''}+f^{tS''}]<0,$

$\phi(.)_{R^tL^t}=-Pf^{tS''},$

$\phi(.)_{L^tR^n}=Pf^{nS''},$

$\phi(.)_{L^tR^t}=-Pf^{tS''},$

$\phi(.)_{L^tL^t}=P[f^{tS''}+f^{nS''}]<0,$

The comparative static equation for the effect of a change in the price of Roundup Ready seeds (w^R) on the portion of land allocated to the cultivation of Roundup Ready under no-till, that cultivated under tillage technology, and the impact of the Roundup Ready input price change on the land investment allocation to no-till and tillage technologies can be obtained by totally differentiating the first order conditions with respect to (w^R).

Assuming that $dP = d\bar{L} = dw^S = dw^t = dw^n = 0$, this yields the following results;

$$[f^{nR''} + f^{nS''}]\frac{dR^n}{dw^R} + f^{nS''}\frac{dL^t}{dw^R} = 1, \tag{10}$$

$$[f^{tR''} + f^{tS''}]\frac{dR^t}{dw^R} - f^{tS''}\frac{dL^t}{dw^R} = 1, \tag{11}$$

$$f^{nS''}\frac{dR^n}{dw^R} - f^{tS''}\frac{dR^t}{dw^R} + [f^{nS''} + f^{tS''}]\frac{dL^t}{dw^R} = 0. \tag{12}$$

Solving this system of equations using Cramer's rule we have:

$$\begin{bmatrix} f^{nR''} + f^{nS''} & 0 & f^{nS''} \\ 0 & f^{tR''} + f^{tS''} & -f^{tS''} \\ f^{nS''} & -f^{tS''} & f^{nS''} + f^{tS''} \end{bmatrix} \begin{bmatrix} \frac{dR^n}{dw^R} \\ \frac{dR^t}{dw^R} \\ \frac{dL^t}{dw^R} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} \tag{13}$$

Solving for the determinant of matrix H yields,

$$|H| = \left(f^{nR''} + f^{nS''} \right) \begin{vmatrix} f^{tR''} + f^{tS''} & -f^{tS''} \\ -f^{tS''} & f^{nS''} + f^{tS''} \end{vmatrix} + \left(f^{nS''} \right) \begin{vmatrix} 0 & f^{nS''} \\ f^{tR''} + f^{tS''} & -f^{tS''} \end{vmatrix} .$$

Therefore,

$$\begin{aligned} |H| = \left\{ f^{tR} + f^{tS} \right\} \left[\left(f^{nR} + f^{nS} \right) \left(f^{nS} + f^{tS} \right) - \left(f^{nS} \right)^2 \right] \\ - \left(f^{nR} + f^{nS} \right) \left(f^{tS} \right)^2 \ . \end{aligned} \tag{14}$$

However by young's theorem,

$f^{tS} = f^{tS}$ and $f^{nS} = f^{nS}$.

From equation (14), $|H|$<0, implies that $\left(f^{nR} + f^{nS} \right) \left(f^{nS} + f^{tS} \right) - \left(f^{nS} \right)^2$>0. This condition will ensure that the second order condition for concavity is met. However even though it can be shown that the following are true,

$\left| H_1 \right| = \left(f^{nR} + f^{nS} \right) < 0$ and $\left| H_2 \right| = \left(f^{nR} + f^{nS} \right) \left(f^{tR} + f^{tS} \right) > 0$, it is difficult to determine the sign of the determinant of H applying the cited equation. It is however easy to derive the overall sign with a little manipulation of the equation below derived from equation (14).

$$
\begin{aligned}
|H| &= \left(f^{nR''} + f^{nS''}\right)\left[\left(f^{tR''} + f^{tS''}\right)\left(f^{nS''} + f^{tS''}\right) - \left(f^{tS''}\right)\left(f^{tS''}\right)\right] \\
&\quad - \left(f^{nS''}\right)\left(f^{nS''}\left\{f^{tR''} + f^{tS''}\right\}\right).
\end{aligned} \tag{15}
$$

Expanding the equation above yields,

$$
\begin{aligned}
|H| &= \left(f^{nR''} + f^{nS''}\right)\left[\left(f^{tR''}.f^{nS''} + f^{tR''}.f^{tS''} + f^{tS''}.f^{nS''}\right)\right] \\
&\quad - \left(f^{nS''}\right)^2\left\{f^{tR''} + f^{tS''}\right\}.
\end{aligned} \tag{16}
$$

With a little manipulation and re-arrangement of equation (16), we can thus infer that,

$$
|H| = \left(f^{tR''}.f^{nS''}\right)\left(f^{nR''} + f^{tS''}\right) + \left(f^{nR''}.f^{tS''}\right)\left(f^{tR''} + f^{nS''}\right) \;<\; 0 \tag{17}
$$

since $f^{nR''} < 0,\; f^{tR''} < 0, f^{nS''} < 0,$ and $f^{tS''} < 0$.

Subsequently using equation 13 and the derivatives from equations 14-17, the effect of a change in the input price for Roundup Ready soybean on acreage allocation of Roundup Ready under no-till can be determined by;

$$
\frac{dR^n}{dw^R} = \frac{\left(f^{nR''} + f^{nS''}\right)\left(f^{nS''} + f^{tS''}\right) - \left(f^{tS''}\right)^2 - f^{tS''} f^{nS''}}{|H|} \quad \stackrel{<}{>} 0 \tag{18}
$$

The sign of the denominator of equation (18) is obviously negative as shown earlier on. However, the numerator of equation (18) is not determined thus making the overall effect of a change in the input price for Roundup Ready soybean on acreage allocation of Roundup Ready under no-till, indeterminate. A careful consideration of the numerator however, can allow us to assume or determine the sign of the numerator by imposing some logical assumptions and conditions on the derivatives, thus resolving the ambiguity of overall sign of equation (18). Simplifying the numerator of equation (18) we derive that it is equal to:

$$\left(f^{nR''}.f^{nS''}\right)+\left(f^{nR''}.f^{tS''}\right)+\left(f^{nS''}\right)^2-\left(f^{tS''}\right)^2, \tag{19}$$

and therefore it is equivalent to,

$$\left(f^{nR''}.f^{nS''}\right)+\left(f^{nR''}.f^{tS''}\right)+\left(f^{nS''}+f^{tS''}\right)\left(f^{nS''}-f^{tS''}\right). \tag{20}$$

Since it is expected that the overall sign of equation (18) will be negative, equation (20) will have to be positive. Given that $f^{nR''}<0$, $f^{nS''}<0$ $f^{tR''}<0$, and $f^{tS''}<0$ it implies that $\left(f^{nS''}-f^{tS''}\right)$ has to be negative or $\left(f^{nR''}.f^{nS''}\right)+\left(f^{nR''}.f^{tS''}\right)+\left(f^{nS''}\right)^2>\left(f^{tS''}\right)^2$ for equation (20) to be positive.

Furthermore, the effect of a change in the input price for Roundup Ready soybean on acreage allocation of Roundup Ready under tillage is also determined by:

$$\frac{dR^t}{dw^R}=\frac{-\left(f^{nR''}+f^{nS''}\right)\left(f^{nS''}+f^{tS''}\right)+\left(f^{nS''}\right)^2+f^{nS''}f^{tS''}}{|H|}\ \substack{\le \\ >}\ 0 \tag{21}$$

Therefore we derive that the overall impact of a change in the input price of Roundup Ready on the acreage allocated to Roundup Ready soybeans is:

$$\frac{d(R^n+R^t)}{dw^R}=\frac{\left(f^{nS''}\right)^2-\left(f^{tS''}\right)^2}{|H|}\ \substack{\le \\ >}\ 0. \tag{22}$$

Hence in analyzing the total effect of a change in Roundup Ready input cost, we can infer that equation (18) and (22) are negative if the absolute value of a change in the marginal product of land under no-till is greater than the marginal product of land under tillage when Roundup Ready soybean acreages changes. In other words, it must be the case that the marginal product of land under no-till is more sensitive to a change in Roundup Ready acreages than the marginal product of land under tillage i.e. $\left|f^{nS''}\right| > \left|f^{tS''}\right|$.

Similarly the effect of a change in the input price for Roundup Ready soybean on acreage allocated to no-till technology is determined by;

$$\frac{dL^n}{dw^R} = -\frac{dL^t}{dw^R} = \frac{f^{nS''}\left(f^{tR''} + f^{tS''}\right) - f^{tS''}\left(f^{nR''} + f^{nS''}\right)}{|H|} \lesseqgtr 0 . \tag{23}$$

Therefore simplifying equation (23) above results in,

$$\frac{dL^n}{dw^R} = -\frac{dL^t}{dw^R} = \frac{\left(f^{nS''}.f^{tR''}\right) - \left(f^{tS''}.f^{nR''}\right)}{|H|} \lesseqgtr 0 . \tag{24}$$

The overall sign of the comparative static above is ambiguous. This is because there is an interaction effect between the Roundup Ready seed adoption and the marginal productivity of land under no-till and tillage. The overall sign of $\frac{dL^n}{dw^R}$ therefore depends on the direction of the marginal impact that an increase in Roundup Ready acreage has on the marginal product of land under tillage and no-till. Intuition from our graphical analysis suggests that an increase in the input price for Roundup Ready soybean is likely to decrease the amount of no-till land needed for its cultivation. Therefore it is expected that equation (24) will have a negative sign. This will be true if the right hand side of the equation of the numerator is greater than the equation on the left hand side. From equation (24), it is possible to construct an equation that defines the cross-elasticity between no-till and Roundup Ready as below;

$$\eta_{L^n w^R} = \frac{dL^n}{dw^R} \cdot \frac{w^R}{L^n} = \frac{\left(f^{nS''} . f^{tR''}\right) - \left(f^{tS''} . f^{nR''}\right)}{|H|} \cdot \frac{w^R}{L^n}, \tag{25}$$

such that if $\eta_{L^n w^R}$ <0 then it suggests some complementarity between the two technologies.

Thus even though the sign of $\eta_{L^n w^R}$ does not directly depend on the marginal product of land, it indirectly depends on the interaction effect that an impact of a change in roundup acreages under tillage and no-till has on the rate of change of the marginal productivity of land. Assuming that the acreage of land under tillage is held fixed, adopting roundup technology simultaneously with no-till will imply an increase in the acreage of Roundup Ready soybeans under no-till and a resultant decrease in the acreage available for the cultivation of traditional soybeans. This implies that under the assumption of diminishing marginal returns, then in the short run, it could result in the fall of $f^{nS'}$. This invariably makes $f^{nS''}$ more negative (or more positive in absolute terms) and possibly makes the left hand side of equation (24) and (25) i.e $\left(f^{nS''} . f^{tR''}\right)$ greater than the right hand side $\left(f^{tS''} . f^{nR''}\right)$. If this condition prevails, the numerator of the two equations will have a positive sign thus creating the likelihood that the overall sign of equations (24) and (25) will be negative. However, if the rate of decrease in $f^{nR''}$ is faster than that of $f^{tR''}$ with the adoption and further increase in acreages for

Roundup Ready soybeans and no-till, it will offset the impact of the negativity of $f^{nS''}$ in equations (24) and (25) and the overall sign will still remain ambiguous.

To investigate the effect of a change in no-till technology input price on the acreage allocation to no-till and Roundup Ready technologies, the following simultaneous equations are solved:

$$[f^{nR''} + f^{nS''}]\frac{dR^n}{dw^n} + f^{nS''}\frac{dL^t}{dw^n} = 0, \tag{26}$$

$$[f^{tR''} + f^{tS''}]\frac{dR^t}{dw^n} - f^{tS''}\frac{dL^t}{dw^n} = 0, \tag{27}$$

$$f^{nS''}\frac{dR^n}{dw^n} - f^{tS''}\frac{dR^t}{dw^n} + [f^{nS''} + f^{tS''}]\frac{dL^t}{dw^n} = -1. \tag{28}$$

Solving this system of equations by applying Cramer's rule we have:

$$H = \begin{bmatrix} f^{nR''} + f^{nS''} & 0 & f^{nS''} \\ 0 & f^{tR''} + f^{tS''} & -f^{tS''} \\ f^{nS''} & -f^{tS''} & f^{nS''} + f^{tS''} \end{bmatrix} \begin{bmatrix} \frac{dR^n}{dw^n} \\ \frac{dR^t}{dw^n} \\ \frac{dL^t}{dw^n} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix} \tag{29}$$

where the following holds $|H_1| < 0, \quad |H_2| > 0, \quad |H_3| < 0.$

The comparative statics results derived indicate that:

$$\frac{dR^n}{dw^n} = \frac{f^{nS''}\left(f^{tR''} + f^{tS''}\right)}{|\mathrm{H}|} < 0, \tag{30}$$

$$\frac{dR^t}{dw^n} = \frac{-f^{tS''}\left(f^{nR''} + f^{nS''}\right)}{|\mathrm{H}|} > 0, \tag{31}$$

$$\frac{d(R^n + R^t)}{dw^n} = \frac{f^{nS''}\left(f^{tR''} + f^{tS''}\right) - f^{tS''}\left(f^{nR''} + f^{nS''}\right)}{|\mathrm{H}|} \gtreqless 0, \tag{32}$$

Therefore,

$$\frac{d(R^n + R^t)}{dw^n} = \frac{f^{nS''} . f^{tR''} - f^{tS''} . f^{nR''}}{|\mathrm{H}|} \gtreqless 0, \tag{32'}$$

$$\frac{dL^t}{dw^n} = -\frac{\left(f^{nR''} + f^{nS''}\right)\left(f^{tR''} + f^{tS''}\right)}{|\mathrm{H}|} > 0, \tag{33}$$

$$\frac{dL^n}{dw^n} = -\frac{dL^t}{dw^n} = \frac{\left(f^{nR''} + f^{nS''}\right)\left(f^{tR''} + f^{tS''}\right)}{|\mathrm{H}|} < 0. \tag{34}$$

Considering equation (30), it is easy to determine that the overall sign of a change in the price of inputs invested into no-till on no-till Roundup Ready soybean is negative. This is because the sign of the second order derivatives from economic theory are;

$f^{nS''} < 0,\ f^{tR''} < 0,\ f^{tS''} < 0,$ and $f^{nR''} < 0$ therefore making the numerator of equation (30) positive. Hence since $|H|$ is negative from the second order conditions, it is possible to infer that $\frac{dR^n}{dw^n} < 0$. In fact intuition supports this conclusion in the sense that we would expect that this would be the case if there is some synergistic effect between the cultivation of Roundup Ready soybeans under no-till technology and that tillage would not necessarily be a better substitute for no-till when roundup ready is being cultivated. Therefore if there is a greater benefit planting Roundup Ready soybeans under no-till, which is more cost effective, then when the price of no-till input increases, the acreage of land allocated for planting Roundup Ready soybeans is likely to fall.

With the assumptions made about the production function and from the second order conditions, it is obvious that equation (31) has a positive sign. That is, even though no-till and tillage may not yield the same profit margin for the cultivation of soybean, for a fixed portion of land the farmer has an incentive to divert land to other uses such as tillage if the price of no-till inputs increases. Equations (33) and (34) also have the expected sign. These equations also support the fact that if it becomes costly to cultivate using no-till technology, farmers will divert their land investment resources into cultivation using tillage and vice versa.

With respect to the impact of a change in no-till input prices, even though it was relatively easier to determine the effect of the direction of the change on Roundup Ready acreage under no-till technology and tillage technology individually, the overall sign of equation (32)' is ambiguous. In spite of the fact that the denominator is known to be negative, the sign of the numerator is indeterminate. By inspection, it can be realized that the effect of a change in no-till input prices (dw^n) on Roundup Ready soybeans under tillage and no-till technologies (i.e. R_t and R_n respectively) depends on the change in the marginal products of all the component technological combinations employed by the farmer that is $f^{nS''}$, $f^{tR''}$, $f^{tS''}$, and $f^{nR''}$. In other words, the ability to determine the overall impact of dw^n *on* $d(R_t + R_n)$ depends on how sensitive the marginal products are to such changes. Consequently, we cannot easily tell whether (32)' is positive or negative, however by inspection it is possible to infer that equation (32)' will be positive if the second term in the numerator is greater than the left first.

Subsequently, for $\dfrac{d(R^n + R^t)}{dw^n} > 0$, $f^{tS''}.f^{nR''} > f^{nS''}.f^{tR''}$ has to hold

Otherwise if $f^{tS''}.f^{nR''} < f^{nS''}.f^{tR''}$ then $\dfrac{d(R^n + R^t)}{dw^n} < 0.$

This seems to suggest that there is some degree of response by R^t when R^n responds to changes in w^n, which may offset each other equally or not. Depending on which outweighs the other, the sign of equation (32)' will be positive or negative.

Chapter 4

4.1 Data Sources and Questionnaire Information

4.1.1 *Data Source*

The data used in this study are survey data. The survey was conducted by Doane Marketing Research, a firm that specializes in agricultural research. This was conducted in all the 50 states of the United States. In all there were about 610 respondents in the survey, 525 in the Midwest and 85 respondents in the south. These were farmers who planted at least 250 acres of soybeans in the year 2002.

4.1.2 *The Questionnaire*

Soybean growers were asked questions about the soybean varieties they planted, the acreages they owned or leased, how much of the area was used for RR soybeans and traditional varieties and average yield per acre on both RR and non-RR soybeans to mention a few. The researchers also sought to find out information on the cost of operation of each respondent, farmer's educational level and farm experience. They were also asked detailed questions about the weed control systems they were employing and how much time they spent on the field including the number of passes of farm implements on both their RR soybean and non-RR soybean acres.

With regard to seed costs, farmers were asked to provide an estimate of seed cost per acre for planting RR soybean varieties and the traditional varieties. This was expected to be relatively higher for RR soybean varieties since it usually includes a technology fee. Regarding tillage costs, farmers were asked to estimate by how much their tillage costs change when they shift from conventional tillage to reduced-till, including no-till. The question was asked in terms of time savings (a convenience factor) in moving from conventional tillage to reduced-till (including no-till). The growers were therefore asked to quote dollar per acre estimates ($/acre) on the time savings from using no-till. Furthermore, to fully assess the convenience benefit of a given farming practice (for example, the flexibility of herbicide application rates, time of application etc.), the growers were made to provide per acre dollar estimates on time, equipment and labor savings, the amount of minutes saved per acre per season by comparing the two seed types used.

The questionnaire also sought to provide information on market uncertainty costs, seeds saved cost (given that farmers have to purchase new planting seeds for RR soybean cultivation, as opposed to the replanting of old seed stock from saved seeds in the traditional cultivation practice) and harvest costs per acre related to RR soybeans and the traditional varieties. Weed costs were assessed by inquiring from farmers of their herbicide material (including surfactants, Roundup costs and other herbicides used on RR soybeans) and application costs per acre. The question of the whether there are any human and environmental benefits from switching to RR soybean varieties was also asked, and farmers were further asked to place a dollar on these gains if any.

Farmers were also made to specify changes in their field treatments in terms of the number of passes they made with different tillage equipment (i.e. moldboard plow, chisel plow, and disc). They were also asked to provide the dollar value estimates on the environmental benefits of using reduced tillage.

In a bid to understand the possible positive relationship between the use of a given seed type and a tillage practice, the respondents were asked to provide information on the order of their decision, whether they chose the seed type first before the tillage type or vice versa, or simultaneously.

Information regarding soybean yield was also assessed in the questionnaire. It was realized that whiles some farmers plant Roundup Ready soybeans only, others plant the traditional varieties only and a good proportion plant both RR and traditional soybean varieties. Information was gathered on the full season and double-cropped soybeans. To measure soybean yield farmers were asked of their yield per acre in 2001 and 2002 for the traditional, RR soybean varieties, and for full-season and double-cropped soybeans.

Furthermore, farmers were classified into different categories; those who used RR soybeans only, traditional soybeans only or both RR and traditional soybeans. The survey also provided information on the percentage of the farmers' planted acreages that were allocated for RR soybeans and no-till (RR_P02_NT), RR soybeans and conventional tillage (RR_P02_CT), traditional soybeans and no-till (NR_P02_NT) and finally traditional soybeans and conventional tillage (NR_P02_CT) technologies in the year 2002.

The demographic characteristics of the farmers surveyed include percentage of time spent in farming versus off-farm activities, income, years of formal education, and years of farming experience. While information gathered on farm characteristics include total farm acres, total crop acres, acres in soybeans and the percentage of soybean acres planted using RR soybean seeds.

4.1.3 Survey Summary Results

Table 1 below reports information on the acreage of land owned or leased and the percentage of acres used for Roundup Ready in the Midwest and the southern soybean growers.

Table 1. Farm Acreage Owned, or Cultivated with Roundup Ready Soybeans

Farm Acres in 2002	1153.56
Farm Acres Rented	619.53
Farm Acres Owned	534.03
Total Crop Acres in 2002	993.74
Total Soybean Acres in 2002	476.15
Percent Soybean Acres in 2002	48%
Percent Soybean Acres Used for Roundup Ready in 2002	72%
Percentage of Southern Growers who Own 100% of Land	19%
Percentage of Southern Growers who Own 50% of Land	11%
Percentage of Growers in Midwest who Own 100% Land	27%
Percentage of Growers in Midwest who Own 50% Land	4.5%

It is shown in table 1 that of the farms surveyed, the average farm size used for crops was about 993 acres and a mean of 1,154 acres in total farm land operated. Of the total land, approximately 46% is owned and about 48% of all crop acres are used for soybeans. Approximately 19% of southern soybean growers owned 100% of the land used, about 11% of respondents in this region owned only 50% of land whiles others owned different proportions and were tenants on other plots they used. On the other hand, in the mid-west, 27% of farmers own their land and only 4.5% owned 50% of the land used for roundup ready soybean. It is also indicated in table 1 that about 72% of soybean acres was planted to RR soybean varieties but only 59% was reported in 2001. The survey revealed that about 60.5% of the respondents adopted Roundup Ready soybean technology in 2002. Of this 57.9% cultivated only Roundup Ready and approximately 2% planted both Roundup Ready soybean and non-Roundup Ready varieties.

The data were also analyzed for information regarding soybean growers in different regions. The distribution of farmers in the two regions is shown in tables 2a and 2b below.

Table 2a. The Distribution of the Number of Farms Surveyed in the South

State	*No. of Farms (85)*
Alabama	2
Arkansas	26
Kentucky	12
Louisiana	7
Mississippi	12
North Carolina	12
South Carolina	4
Tennessee	10

Table 2b. The Distribution of the Number of Farms Surveyed in the Midwest

State	*No. of Farms (525)*
Iowa	95
Illinois	93
Indiana	50
Kansas	27
Michigan	19
Minnesota	62
Missouri	42
Nebraska	44
Ohio	41
South Dakota	39
Wisconsin	13

Information collected indicated that soybean growers who responded were basically concentrated in the southern states (i.e. Alabama, Arkansas, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee) and the mid-west states (including: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin). It is also important to note that more responses were obtained from the Midwest region, with 525 respondents and only 85 farms from the southern region. In the south, the concentration of farms was higher in Arkansas (26 farms), followed by North Carolina, Kentucky, and Mississippi each with 12 farms reported.

On a slightly different note, the data from the survey showed that of those who planted 100% Roundup Ready soybeans, the results were quite comparable in both regions, 59% of respondents in the southern states fully adopted Roundup Ready as opposed to approximately 60% in the mid-west. With respect to the farmer's intended acreage for 2003, it was realized that respondents in the mid-west plan to use at least 61% of land for roundup ready and information from southern soybean growers showed that the intended acreage for 2003 Roundup Ready acreage was no more than 59% percent of land. This shows that there was not a significant change in acreage comparing the Roundup Ready acreage in 2002 to their intended acreages in 2003. Whiles there was an increase of about 3.7% in acreage of land allocated for the planting of both Roundup Ready soybeans and non-roundup ready varieties. Interestingly, the survey showed that in general farmers who responded intend to utilize about 73% of their soybean acreages for the cultivation of Roundup Ready only in 2003, which is an increase of about 1% in the portion of land used in 2002.

Table 3. Percentage of Farmers Reporting Some Benefit from Roundup Ready Soybeans

Type of Benefit	***Human Safety***	***Environmental Benefits***	***Convenience Benefits***	***Equipment Savings***	***Labor Savings***
Number of Farms Responding	458	449	437	528	429
% Reporting Some Benefits	57%	62%	56%	49%	60%

Regarding the different benefits identified in the survey, it is seen from table 3 above that more than half of the number of Roundup Ready soybeans growers (about 57%) report some human safety benefits, 62% reported environmental benefits, and 56% some convenience benefits from using Roundup Ready soybean varieties. Subsequently when asked about the value farmers would place on the human and environmental safety of Roundup Ready soybeans, about 1% of respondents indicated that there was a $20 value in terms of its safety on humans and the environment. Similarly at least 1% of growers in the mid-west placed a value of $40 on its (Roundup Ready soybeans) safety as far as farm operator and worker safety are concerned.

In spite of the benefits of planting Roundup Ready soybeans, some farmers also stated reasons why they did not grow 100% Roundup Ready soybean. A summary of the percentages is presented in table 4 below.

Table 4. Farmer's Reasons for Not Planting Total Acres of Land With Roundup Ready Soybean

Reason	***Percentage of Farmers (n-241)***
High Cost of Seed	19%
Premium Paid to Grow Traditional Soybeans	12%
Higher Yields With Traditional Soybean	11%
Too Much Market Uncertainty	9%
Lack of Market Acceptance	7%

Table 4. Continuation

Reason	***Percentage of Farmers (n-241)***
Preference for the Use of Saved Seeds	5%
Unsatisfactory Technology Fees	5%
Other Reasons	32%

Of the responses from 241 farmers who responded in the survey, 19% of respondents stated that the high seed cost of Roundup Ready soybeans is a reason for not growing 100% Roundup Ready soybeans. About 12% of all farmers also argued that they are being paid a premium to plant the traditional varieties. Some also alluded to the fact that they were getting relatively higher yields from the traditional soybean varieties. These formed about 11% of the respondents. Finally, about 9% of the farmers revealed that market uncertainties and restrictions on the Roundup Ready soybean variety diminished the per acre value of growing Roundup Ready soybean. In fact roughly 31% of farmers in the south argued that market uncertainties and seed restrictions can possibly decrease the per acre value of planting Roundup Ready by at least $10. The same conclusion was made by 26% of the farmers in the mid-west states. About 32% of the respondents cited 'other' (a non-identified reason) as their justification for not planting 100% RR soybeans.

With respect to the amount of time spent on crop production, responses from the survey suggest that while farmers who planted non-roundup ready soybean varieties spent about 80% of their time on crop production, Roundup Ready soybean adopters saved about 3% less of the time spent on crop production by non-adopters (i.e. Roundup Ready soybean adopters spent on average 77% of their time on crop production). In per acre dollar values, Roundup Ready soybean adopters indicated that they saved about 19.9 minutes per acre (for a stated value of $5.6/acre of time savings); equipment savings is also valued at $4.3/acre.

On the issue of the tillage practices used by farmers, researchers including Marra et al. (2004) agree that tillage trips decreases as the percentage of acres in no-till increases. Moreover, the value of time saved in tillage activities increases as farmers shift from traditional soybean to Roundup Ready soybean varieties. Growers surveyed indicated that there are about 24% fewer tillage passes using Roundup Ready soybeans than when planting traditional soybeans. In fact in a recent study Marra et al. (2004) calculated that the average number of tillage passes per season for non-RR soybeans was 1.73 per acre, while that for Roundup Ready soybeans was 1.39 per acre for the 2001 and 2002 seasons.

Furthermore, on the question of the type of tillage practice used for Roundup and non-Roundup Ready Soybeans, responses from farmers surveyed are reported in table 5 and 6 respectively.

Table 5. Percentage of all Soybean Acres Used for Roundup Ready Soybean and the Type of Tillage Technology

Type of Tillage System	***Percent RR Soybean Acres (2001)***	***Percent RR Soybean Acres (2002)***
Conventional Till	24%	23.5%
Reduced Till	34%	35%
No-till	41.6%	41.4%

Table 6. Percentage of all Soybean Acres Used for Non-RR Soybean and the Type of Tillage Technology

Type of *Tillage System*	***Percent of Non-RR Soybean Acres (2001)***	***Percent of Non-RR Soybean Acres (2002)***
Conventional Till	36.9%	36.9%
Reduced Till	34%	30.9%
No-till	29%	32%

Generally, the survey revealed that in 2001 about 41% of soybean acres was used for Roundup Ready soybeans under no-till, which is quite comparable to 41.40% in 2002. On the other hand the cultivation of Roundup Ready soybeans using reduced till and conventional till were about 34% and 24% in 2001, with 35% and 24% in 2002 respectively. On the acres used for non-Roundup Ready soybeans, growers reported using approximately 29% (in 2001) and 32% (in 2002)of soybean acres on no-till, while 34% (comparable to the Roundup Ready acreage under reduced till in 2001) was used on reduced till in 2001. However, the percentage of soybean acres used for non-Roundup Ready soybeans and reduced till was slightly lower in 2002 (30.9%), although the percentage of non-Roundup Ready soybean acres under conventional till remained fairly constant at 36.90% during the 2001 and 2002 cropping seasons as seen in tables 5 and 6.

Of the respondents answering the question regarding the order in which the seed type and tillage practice were chosen, about 65% of full adopters indicated that they made the seed type decision first or at the same time (simultaneously) with the tillage type decision. Interestingly 66% of non-adopters also reported that they made the seed type decision before or at the same time as the tillage decision. Though not substantially, the data suggests that the tillage choice decision is made after or simultaneously with the seed type choice thus, there is no substantial difference between adopters and non-adopters in the ‘tillage type-seed type’ choice behavior (Marra et al., 2004).

Table 7 below shows the summary of the results of the survey in response to the question of the costs involved in growing Roundup Ready soybeans and non-Roundup Ready soybeans with respect to the procurement of planting seeds, herbicide products and application costs as well as the harvesting costs for the respective seed technologies.

Table 7. Average Cost of Farm Activity / Material Cost by Seed Technology Type

Farm Activity/ Material	**Cost ($/Acre) using:** ***RR Soybeans***	 ***Non-RR Soybeans***
Seed	24.12	14.98
Harvesting	19.26	18.99
Herbicide Material	15.36	23.94
Herbicide Application	6.01	7.02

Estimates of the costs reveal that on average the difference between non-Roundup Ready soybeans cost and Roundup Ready soybeans cost is approximately -$9.02 which is expected since farmers pay relatively more for Roundup Ready soybean seeds. However, there isn’t much difference in harvesting cost comparing the two technologies. It is quite evident that herbicide product costs are relatively lower on the Roundup Ready soybean acres as reported by many researchers for example, Carpenter and Gianessi (2001) who found lower weed control costs associated with Roundup Ready soybeans compared to the traditional soybean varieties. The value of the estimated difference in herbicide product cost is approximately $8.68 per acre. Furthermore, the herbicide application cost is found to be lower on Roundup Ready soybean acres than on the traditional varieties, with a difference of about $1.40 per acre of soybean planted.

Table 8. Demographic Characteristics of Survey Respondents

Variable Description	***Mean Value of Responses***
Year Born	1946
Years of Formal Education	13
Years of Farming Experience	33
Percentage of Time Spent in Farming	90.13
Percentage of Time Spent on Crops	78.5

The demographic characteristics of the participants in the survey are presented in table 8 above. Basically farmers were asked questions about their age, education, experience, and farm income. The average age of the respondents was 56 at the time of the survey, and the number of years of experience was about 33 years. The average number of years of experience is about 13 years. On average respondents also reported a mean in range of $10,000-19,000. Other information gathered includes the percentage of time spent farming. It was gathered that on average growers spent about 90% of their time on farming activities as opposed to off-farm activities. However, 78% of their farming time is spent on crop production activities.

4.1.4 *Explanatory Variables Used for the Empirical Study of the Factors Influencing Technology Adoption (Data Description & Expected Signs)*

In the current study, the factors hypothesized to influence the simultaneous adoption of no-till and RR soybeans include but are not limited to: total acreage/farm size, land tenure, experience and farmer attitudes towards risk. Rogers (1995) also identifies time savings and costs as technology attributes that affect its adoption. These will also be considered as part of the variables defined in table 9. It is important to note that table 9 presents the descriptive statistics of the dependent and explanatory variables used in this study.

With regard to the effect of farm size on the adoption of agricultural technologies, Marra and Carlson (1987) have provided evidence in support of the hypothesis that the adoption of new innovations tend to take place earlier on larger farms than on smaller farms. Just, Zilberman and Rausser (1980) also noted that given the uncertainty and fixed transaction and information costs associated with a new innovation, there is a critical limit on farm size that prevents small farms from adopting new technologies. They argue that as these costs increase, the critical size also increases. Therefore new innovations with large fixed transactions or information costs are less likely to be adopted by smaller farms.

In this research, farm size will be determined by the total crop acres in 2002, which we propose to have a positive impact on the adoption of the two technologies. In the current study, the variable FARM_A02 (the total crop acres used in 2002) is used to capture the effect of farm size on the simultaneous adoption of RR soybean and no-till technology. The variable FARMACSQ is the square of the explanatory variable FARM_A02.

The survey also revealed that farmers either owned or leased the land used to cultivate soybeans. Different empirical results obtained by researchers have spawned an enormous amount of debate on the effect of land ownership on adoption of technologies (eg., Feder et al., 1985). Some researchers for example, Bultena and Hoiberg (1983) found no support for the proposition that land tenure has a significant effect on the adoption of conservation tillage. Fernandez-Cornejo and McBride (2002) have attributed these inconsistencies to the differences in the nature of the technologies. They argue that if an innovation requires investments that are tied to the land tenants are less likely to adopt. This seems to imply that land tenure may not affect the adoption of RR per say but considering its simultaneous adoption with no-till technology it might have a significant impact on the decision to adopt the technologies. It is therefore hypothesized in this study that land ownership will encourage the adoption of no-till and RR soybean technologies.

The variable PCTOWNED has been assigned to capture the impact of land ownership on the adoption of the two technologies. It is expected that the land owners will be more likely to adopt new technologies as opposed to tenants.

Farmers possessing greater human capital, technical skills and innovative ability are more likely to adopt new innovations. In this study, the availability of human capital is indicated by the number of years spent farming and the level of education. A higher level of education (EDUC) is therefore expected to increase a farmer's ability to obtain, process and use information pertaining to the use of RR soybeans and no-till. The explanatory variable EDUC2 is obtained by taking the square of EDUC. It is hypothesized that the level of education is likely to induce the adoption of the two technologies in a positive way.

The variable FARMYEARS used in this study represents the number of years a farmer has been operating a farm. It is hypothesized that the experience gained by farmers is likely to increase the probability of the adoption of at least one of the two technologies or the two simultaneously.

TCOST_DIF, is a variable that represents the average total costs of adopting the technologies. It was computed by summing the average per acre cost of labor and equipment, herbicides products and application, harvesting and soybean seed costs for RR and non- roundup ready and finding the difference between them.

It is expected that an increase in the average cost of operation per acre will decrease the probability of adopting the new technology.

VTIME_RR designates the value of time-savings per acre. In the survey, farmers provided information on how much time they saved per acre in minutes with the RR soybean weed control system as opposed to the use of non-RR soybean weed control routine. Following this they were asked to indicate the value they place on the time saved per acre. It is our hypothesis that, the higher the value placed on time saved, the more likely farmers are to adopt the RR soybeans and no-till technology since proponents of no-till and RR soybeans argue that there is considerable time savings employing these technologies in cultivation instead of traditional ones. McNamara et al. (1991), among others, have provided ample evidence that a farmer's off-farm employment may constrain the adoption of management-intensive technologies because it tends to compete for farm managerial time. However on the contrary, the adoption by households with off-farm employment may be encouraged if the technology is labor or time saving. Therefore due to the managerial simplicity of the two technologies, the percentage of time spent in farming activities compared to off-farm employment (TIME_PF) is hypothesized to be positively related to the odds of the two technologies being adopted.

The extent to which market uncertainties diminish the value of RR soybeans and its market price may also affect the adoption of the technology. In fact the notion that technological innovation is perceived to be more risky than traditional practices may inhibit adoption (Feder et al., 1985). The variable VUNCSEED captures the impact of market uncertainty on the adoption of RR. It represents how much the value of market uncertainties diminishes the per acre value of growing of growing RR soybeans. It is hypothesized to negatively influence the adoption of the technologies.

The added value per acre of human and environmental safety of RR (VHUMENV) is also hypothesized to be positively related to the adoption of the technologies, just as the value of per acre equipment savings (VEQU_RR) is also expected to have a positive impact on the adoption of RR soybean and no-till technologies. The variable (VTIME_RT) represents the per acre value of time savings using reduced till (including no-till). This is expected to have a positive impact on the adoption of no-till. (VENV_RT) and (VCONV_RT) also represent the per acre value of environmental benefits and convenience factors from the use of reduced tillage. These are also part of the non-pecuniary factors used to explain the adoption of no-till technology and are hypothesized to have a positive impact on the adoption of the technology. Table 9 presents a summary of the descriptive statistics of the explanatory variables included in this study.

Table 9. Variable Descriptive Statistics

Variable	Variable Description	N	Mean	Std. Dev.	Min	Max
tcostdif	Average total cost difference between Non-RR & RR soybean inputs ($/acre)	509	0.95	9.58	-52	53
rr_p01	Percentage of total 2001 soybean acres used for RR (%)	610	59.4	42.9	0	100
rr_p02	Percentage of total 2002 soybean acres used for RR (%)	610	72.01	39.83	0	100
rr_p03	Intended Percentage of land for RR variety in 2003 (%)	596	74.1	38.54	0	100
nt_rt_p02	Percentage of total 2002 soybean acres used for not-till (%)	610	81.11	35.59	0	100
nt_rt_p01	Percentage of total 2001 soybean acres used for not-till (%)	469	75.57	41.25	0	100
farm_a02	Total 2002 farm acres of operation (acres)	610	1153.6	987.42	140	7000
pctowned	Percentage of acres owned (%)	610	50.94	34.39	0	100
vtime_rr	Value of time savings under RR soybean variety ($/acre)	429	4.52	6.75	0	30
vequ_rr	Value of equipment savings under RR soybean variety ($/acre)	528	3.3	5.61	0	25
vhumenv	Value of human and environmental benefits for RR soybean ($/acre)	409	4.49	7.91	0	40
vtime_rt	Value of time savings using reduced till ($/acre)	610	10.01	8.61	0	40
vconv_rt	Value of convenience factors under reduced till ($/acre)	497	6.72	8.27	0	35
ylddif	Average yield/acre difference between non-RR and RR soybean	610	1.1	2.36	-21	20
vuncseed	Value of market uncertainty on RR soybean ($)	501	6.02	7.72	0	35

Table 9. (Continued)

Variable	Variable Description	N	Mean	Std. Dev.	Min.	Max.
time_pf	Percentage of work time spent in farming versus off-farm activities (%)	605	90.13	20.98	5	100
educ	Last year of formal education completed (years)	610	13.43	2.12	8	18
region	1if Midwest, 0 if south	610	0.8803	0.32	0	1
farmyears	Number of years of operating farm (years)	608	33.32	11.88	4	78

Chapter 5

Econometric Issues

5.1.1 Introduction

Economists conduct routine tests on data collected, which usually reveals the presence of some form of misspecification that has the potential to render Ordinary Least Squares estimates inefficient, biased and/or inconsistent. In such cases, another estimation method is required to produce consistent and asymptotically efficient estimates.

In this chapter, I will define heteroskedasticity (a common problem in cross-sectional data sets) and also emphasize its possible consequences for Ordinary Least Square estimates. Furthermore, I will discuss some estimation techniques used in detecting heteroskedasticity, and also suggest some remedies available to correct it. Since the present study uses cross-sectional data, it is necessary to test for the problem of heteroskedasticity and subsequently correct the standard errors in order to obtain estimates that are efficient. Finally, the procedure used to detect and cure heteroskedasticity in the data used will also be outlined in this chapter.

5.2 Heteroskedasticity

Under the classical assumptions of the ordinary regression model, it is assumed that the variance of the error term is constant or homogenous across observations, i.e. the errors are thus said to be homoskedastic. Consequently, when this assumption is violated, the errors are said to be heteroskedastic. In the presence of heteroskedasticity, even though the parameter estimates may still be consistent, they are inefficient with wrong standard errors, thereby making the inferences drawn from them possibly misleading.

5.2.1 Visually Assessing Evidence of Heteroskedasticity

There are several methods for testing the presence of heteroskedasticity. This includes: the visual examination of residual scatter plots, the Breusch-Pagan test, White's test and the Goldfeld-Quandt test. Of these, the most common test involves looking for patterns in a plot of the residual from the Ordinary least Squares regression.

The simple acreage model used for the current study is specified as follows:

$$
\begin{aligned}
NT\_RT\_P02 = {} & \alpha_1 + \beta_1 * TCOSTDIF + \beta_2 * RR\_P02 + \beta_3 * NT\_RT - P01 \\
& + \beta_4 * FARM\_A02 + \beta_5 * PCTOWNED + \beta_6 * VTIME\_RR + \beta_7 * VEQU\_RR \\
& + \beta_8 * VHUMENV + \beta_9 * YLDDIF + \beta_{10} * VUNCSEED + \beta_{11} * FARMYEARS \\
& + \beta_{12} * TIME\_PF + \beta_{13} * EDUC + \beta_{14} * REGION + \varepsilon_1.
\end{aligned} \tag{1}
$$

Similarly for RR soybean acreages we have:

$$
\begin{aligned}
RR\_P02 = {} & \alpha_2 + \phi_1 * TCOSTDIF + \phi_2 * RR\_P01 + \phi_3 * NT\_RT\_P01 + \phi_4 * FARM\_A02 \\
& + \phi_5 * PCTOWNED + \phi_6 * VTIME\_RR + \phi_7 * VEQU\_RR + \phi_8 * VHUMENV \\
& + \phi_9 * YLDDIF + \phi_{10} * VUNCSEED + \phi_{11} * FARMYEARS + \phi_{12} * TIME\_PF \\
& + \phi_{13} * EDUC + \phi_{14} * REGION + \varepsilon_2.
\end{aligned} \tag{2}
$$

Terms in equations (1) and (2) are defined as:

NT_RT_P02= Percentage of land used for no-till technology in 2002,

NT_RT_P01= Percentage of land used for no-till technology in 2001,

TCOSTDDIF= Total cost difference between planting RR and conventional varieties,

RR_P02= Percentage of land used for Roundup Ready soybean cultivation in 2002,

RR_P01=Percentage of land used for Roundup Ready soybeans in 2001,

FARM_A02= Total acreage of land used for cultivation of soybeans,

PCTOWNED= Percentage of acreage owned,

VTIME_RR= Value of per acre time-savings cultivating Roundup Ready soybeans,

VEQU_RR= Value per acre of equipment savings for planting Roundup Ready soybeans,

VHUMENV= Value per acre of human and environmental safety of Roundup Ready soybeans,

YLDDIF= Yield difference between Roundup Ready soybean and no-till technology,

VUNCSEED= How much market uncertainties and restrictions on seeds diminish the value of growing RR soybeans per acre,

FARMYEARS= Number Of years of operating a farm,

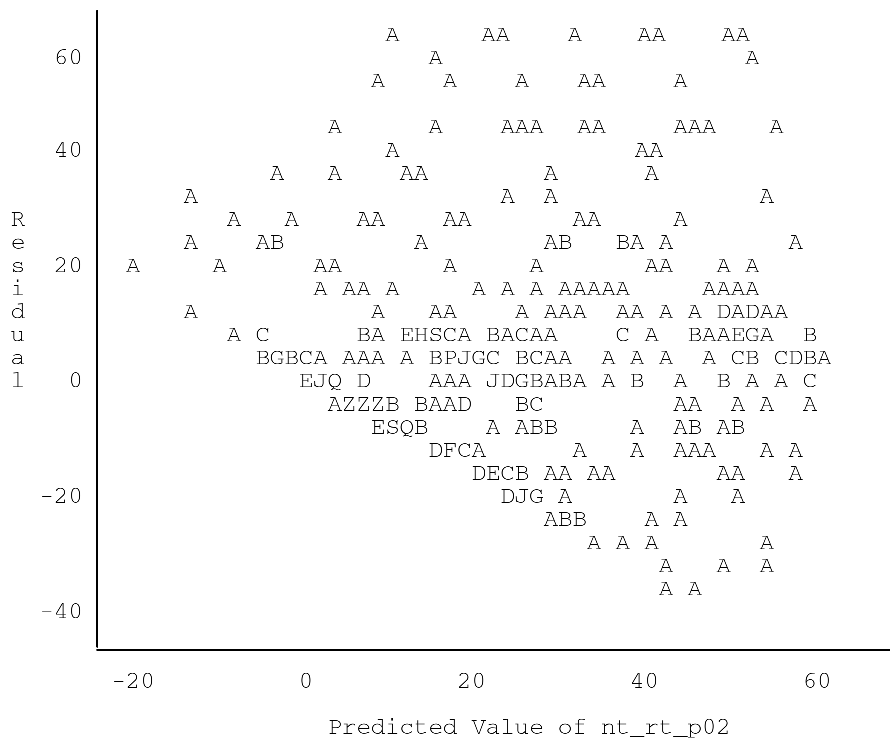
TIME_PF= Percentage of work time spent on farming activities compared to off-farm employment,

EDUC= Last year of formal education completed,

REGION= 1 if Midwest, 0 if South.

An Ordinary least Square (OLS) estimation of equations 1 and 2 above, resulted in estimates that were not economically intuitive and hence unreliable. It was therefore not surprising that a plot of the residual from equation (1) revealed a high degree of heteroskedasticity. In other words, the plot showed a strong fan-shaped pattern of increasing variance with increasing predicted values as shown in the figure 6 below:

Figure 6. Heteroskedastic Funnel-Shaped Graph



This 'fan-shaped' pattern is a sign of heteroskedasticity. However, since the plot of residuals against the predicted value of RR_P02 using equation (2) did not yield the expected diagram (i.e. fan-shape), after testing for heteroskedasticity in the model using the residual plot method, we further tested the null hypothesis of homoskedasticity against the alternative of the presence of heteroskedasticity using the White's test and the Breusch-Pagan test in order to capture the effect of the non-constant residual variance in the model. This was done to further substantiate the evidence provided by the residual plot analysis.

5.2.2 White's Test

This is a more general test because it makes no assumptions about the form of the heteroskedasticity (White 1980). The White's test for heteroskedasticity described in Green (2000, p. 508), is computed by regressing the square of the residuals obtained from the Ordinary Least Squares, $\varepsilon_i^{\ 2}$, on a constant plus the original explanatory variables, their squares, and their cross products. The null hypothesis is that there is no heteroskedasticity, while the alternative hypothesis is that there is heteroskedasticity. If the errors are homoskedastic, then $W=N*R^2$ is chi square distributed with degrees of freedom equal to the number of independent regressors in the second regression, excluding the constant. With N, being the number of observations, a significant value of W, leads to the rejection of the null hypothesis of homoskedasticity. Even though this is a general test that has the advantage of testing for every form of heteroskedasticity, its disadvantage is that it can reject the null hypothesis for reasons other than heteroskedasticity. Thus, the White's test may be significant when the errors are homoskedastic but the model is misspecified in other ways (Thursby 1982).

5.2.3 The Breusch-Pagan Test

Breusch and Pagan in 1979 derived a lagrange multiplier test for heteroskedasticity now known as the Breusch-Pagan test presented in Green (2000, p.509). This procedure tests the null hypothesis that there is no heteroskedasticity against the alternative hypothesis that there is heteroskedasticity.

The steps used to conduct this test in the current study are as follows:

(i) Equation (1) was estimated by Ordinary Least Square to obtain the residuals, ε_i.

(ii) The residuals ε_i^2 were squared.

(iii) An auxiliary regression which is a regression of the squared residuals ε_i^2 on all of the explanatory variables in equation (1) was run as follows:

$$\begin{aligned}\varepsilon_i^2 &= \alpha_1 + \beta_1 * TCOSTDIF + \beta_2 * RR\_P02 + \beta_3 * NT\_RT\_P01 + \beta_4 * FARM\_A02 \\ &+ \beta_5 * PCTOWNED + \beta_6 * VTIME\_RR + \beta_7 * VEQU\_RR + \beta_8 * VHUMENV \\ &+ \beta_9 * YLDDIF + \beta_{10} * VUNCSEED + \beta_{11} * FARMYEARS + \beta_{12} * TIME\_PF \\ &+ \beta_{13} * EDUC + \beta_{14} * REGION + \varepsilon_1.\end{aligned} \tag{3}$$

(iv) The *LM* statistic is constructed as:

$$LM=NR^2.$$

Thus the LM statistic is the product between the sample size N and the R-squared from equation (3). Under the null hypothesis, the test statistic is distributed as chi-square with degrees of freedom equal to the number of independent regressors in the model (which is 14 in this model).

(v) The decision criteria applied to draw inferences was that if the chi-square value exceeds the critical value at 5% level of significance, then the null hypothesis of homoskedasticity is rejected in favor of the alternative hypothesis.

Interestingly, the results of our test shows that both the White's test and Breusch-Pagan test reject the null hypothesis of no heteroskedasticity (homoskedasticity) in favor of the alternative as shown in the table below:

Heteroskedasticity Test Results

Variables	Test	Statistic	DF	Pr > ChiSq
NT_RT_P02	White's Test	222.7	118	<.0001
	Breusch-Pagan	97.05	14	<.0001
	Test	Statistic	DF	Pr > ChiSq
RR_P02	White's Test	414.4	118	<.0001
	Breusch-Pagan	268.6	14	<.0001

This implies that the standard errors of the parameter estimates are incorrect and thus inferences made from the OLS estimates will be misleading. Since the multivariate regressions (1) and (2) displayed significant heteroskedasticity (as shown by the tests), they were considered unreliable as a means to analyze the data. .

5.3 Correcting for Heteroskedasticity

A number of methods have been proposed to correct the problem of heteroskedasticity in a data set. This includes weighted least squares (WLS), feasible generalized least squares (FGLS) and the general methods of moments (GMM) procedure among others. In the next section, I will briefly discuss a couple of these estimation techniques used to cure the problem of heteroskedasticity.

5.3.1. Weighted Least Squares (*WLS*)

This is one of the basic techniques for the estimation of heteroskedastic error models. This econometric procedure presented in Green (2000, p.512), involves the transformation of the regressors in the original equation with the heteroskedastic error to obtain a 'new' error term in the transformed equation which is homoskedastic. This ensures that the estimation of the transformed regression equation is BLUE (Best Linear Unbiased Estimates).

In the *Weighted Least Squares* (WLS) procedure, the transformation process involves the multiplication of the regression equation by weights. For example, assume that the model is specified as:

$$Y_i=\beta_1+\beta_2X_i+u_i \qquad u_i \sim NID\ (0,\ \sigma_i^2). \tag{4}$$

Also assume that the form of the heteroskedasticity is purely multiplicative e.g. $\sigma_i^2=\sigma^2 h_i^m$. Where X_i is the vector of explanatory variables, u_i is the heteroskedastic error term, σ^2 is a constant scale variable with $\sigma^2>0$, and h_i is a variable which may or may not be in the linear equation and m is a pre-specified power (constant). The equation weight, w_i, is thus defined as σ/σ_i. From the assumptions made above, the weights are equal to $1/(h_i^{m/2})$. Hence if m=1, equation (4) is then multiplied by the weights to get the transformed regression equation below:

$$Y_i\, w_i = \beta_1\, w_i + \beta_2 X_i\, w_i + u_i\, w_i.$$

Therefore,

$$\frac{Y_i}{\sqrt{h_i}} = \frac{\beta_1}{\sqrt{h_i}} + \frac{\beta_2 X^*}{\sqrt{h_i}} + \frac{u_i}{\sqrt{h_i}}. \tag{5}$$

This can be written as:

$$Y_i^*=\beta_1 h_i^*+\beta_2 X_i^*+u_i^* \qquad u_i^* \sim NIID\ (0,\ \sigma^2). \tag{6}$$

The Ordinary Least Squares estimation of equation (6) which contains the transformed variables yields the *WLS* estimates of the regression with homoskedastic errors.

5.3.2. Feasible Generalized Least Squares (FGLS)

In the current study, I used the feasible generalized least squares estimation technique in an attempt to cure the problem of heteroskedasticity. Since the variance of the error term is unknown, we follow the FGLS procedure as discussed in Greene (2000, p.469). This section therefore outlines the steps taken to ensure that the regression estimates obtained are asymptotically efficient and consistent.

Using equations (1) and (2), the steps taken to conduct the feasible generalized procedure were as follows:

(i) By the Ordinary Least Squares procedure, I estimated equations (1) and (2) separately.

(ii) The residuals from step (i) above were retrieved and saved.

(iii) The residuals were then squared.

(iv) By creating a new variable equal to the log of the squared residuals, the following regression equation was estimated for the two equations:

$$\begin{aligned}
\ln(\varepsilon_i^2) &= \alpha_1 + \beta_1 * TCOSTDIF + \beta_2 * RR_P02 + \beta_3 * NT_RT_P01 + \beta_4 * FARM_A02 \\
&+ \beta_5 * PCTOWNED + \beta_6 * VTIME_RR + \beta_7 * VHUMENV + \beta_8 * YLDDIF \\
&+ \beta_9 * VUNCSEED + \beta_{10} * FARMYEARS + \beta_{11} * TIME_PF + \beta_{12} * VEQU_RR \\
&+ \beta_{13} * EDUC + \beta_{14} * REGION + v_i. \qquad (7)
\end{aligned}$$

(v) The fitted values from equation (7) i.e. $E[ln(\varepsilon_i^2)]$, were saved.

(vi) By taking the exponentials of the fitted values, I calculated the variance, $\hat{\sigma}^2$.

(vii) The model was then transformed by multiplying $w_i = 1/\hat{\sigma}_i$ through the two equations (1) and (2), and finally the model below was estimated:

$$
\begin{aligned}
NT\_RT\_P02 * \frac{1}{\hat{\sigma}_i} = \frac{1}{\hat{\sigma}_i}[\alpha_1 &+ \beta_1 * RR\_P02 + \beta_2 * NT\_RT\_P01 + \beta_3 * FARM\_A02 \\
&+ \beta_4 * FARM\_A02 + \beta_5 * PCTOWNED + \beta_6 * VTIME\_RT \\
&+ \beta_7 * VCONV\_RT + \beta_8 * VENV\_RT + \beta_9 * FARMYEARS \\
&+ \beta_{10} * TIME\_PF + \beta_{11} * EDUC + \beta_{12} * EDUC2 + \beta_{13} * REGION + \varepsilon_1]
\end{aligned} \tag{8}
$$

and

$$
\begin{aligned}
RR\_P02 * \frac{1}{\hat{\sigma}_i} = \frac{1}{\hat{\sigma}_i}[\alpha_2 &+ \phi_1 * TCOSTDIF + \phi_2 * RR\_P01 + \phi_3 * NT\_RT\_P01 \\
&+ \phi_4 * FARM\_A02 + \phi_5 * FARM\_A02SQ + \phi_6 * VTIME\_RR \\
&+ \phi_7 * PCTOWNED + \phi_8 * VHUMENV + \phi_9 * YLDDIF \\
&+ \phi_{10} * VUNCSEED + \phi_{11} * FARMYEARS + \phi_{12} * TIME\_PF \\
&+ \phi_{13} * EDUC + \phi_{14} * EDUC2 + \phi_{15} * REGION + \varepsilon_2].
\end{aligned} \tag{9}
$$

Chapter 6

6.1 Other Empirical Estimation Models

Empirical models that are used to study the adoption of technologies include simultaneous equation models, probit and logit models. A Tobit model is used to model the individual adoption and the extent of adoption of roundup ready soybean and no-till technology in this paper. It is hoped that this will allow for the comparison of our results from the Tobit model to that of the FGLS estimates, thus verifying the robustness of our results.

The Tobit analysis assumes that the dependent variable has a number of its values clustered at a limiting value, usually zero, and uses all observations, both those at the limit and those above it to estimate the regression line. Since the dependent variable in our model is the amount of land or the portion of the acreage with the technology, the Tobit model is considered to be appropriate to address the issue raised by the question; whether the availability or characteristics of roundup ready soybean seeds (herbicide-tolerant) is encouraging farmers to adopt no-till practices for soybean production.

Furthermore, Feder and Umali (1993) substantiates our argument with the fact that the Tobit technique is sometimes preferable to binary adoption models when the decision to adopt involves a simultaneous decision-making process, especially one regarding the decision to adopt and the intensity of adoption. The Tobit approach has been applied in many studies including the adoption of conservation tillage (Norris and Batie, 1987) and the adoption of alternative crop varieties (Adesinah and Zinnah, 1993).

6.2 The Two-Limit Tobit Procedure

In this stage of our analysis, we use a two-limit Tobit model discussed in Maddala (1992 p. 161) to investigate the individual adoption and the intensity of use of no-till and Roundup Ready soybean technologies. It is preferable to use the two-limit Tobit model because the dependent variable in our model is the proportion of the farmer's total acreage that is used for the new technology (i.e. no-till and Roundup Ready soybean technology). Since the dependent variable has a censored distribution, its values are between 0 and 1 thus allowing the use of the two-limit Tobit model.

The two-limit Tobit model for the adoption component of our model can be represented as:

$$y_i^* = X_i \beta + \varepsilon_i \qquad (i = 1 \ldots N). \qquad (1)$$

where,

N is the number of observations,

y_i is an unobserved latent variable that represents the use (or intensity of adoption) of the new technology by farmer i,

X_i is a vector of independent variables,

β_i is a vector of unknown parameters, and

ε_i is a disturbance term assumed to be independently and normally distributed with mean zero and constant variance σ^2.

Denoting y_i (the proportion of acreage on which a technology is used) as the observed dependent variable, then:

$$y_i = \begin{cases} 0 & if \;\; y_i^* \le 0, \\ y_i^* & if \;\; 0 < y_i^* < 1, \\ 1 & if \;\; y_i^* \ge 1. \end{cases} \tag{2}$$

Using the two-limit Tobit, the extent of adoption of the new technology was regressed on the explanatory variables (the factors hypothesized to influence the adoption of the technology). As shown in Gould et al. (1989), the likelihood function of this model is given by:

$$\begin{aligned} L(\beta, \sigma, y_i, X_i) = & \prod_{y_i=0} F(-X_i \beta / \sigma) \prod_{y_i=y^*} (1/\sigma) f([y_i - X_i \beta]/\sigma) \\ & \prod_{y_i=1} \{1 - F([1 - X_i \beta]/\sigma)\}, \end{aligned} \tag{3}$$

where $F(.)$ is the cumulative normal distribution and $f(.)$ is the normal distribution function (Maddala 1992, p. 161) and σ is the standard error as defined earlier.

6.2.1 McDonald-Moffit Decomposition for a Two-Limit Tobit

Here I follow the argument forwarded by McDonald and Moffit (1980) to demonstrate that the coefficients of the explanatory variable obtained in the two-limit Tobit model used here cannot be interpreted directly as estimates of the magnitude of the marginal changes in the explanatory variables on the expected value of the dependent variable. Although the expected value of the latent variable is $E(y^* | X) = X\beta$ and the marginal effect of a particular X_i on the latent variable is $\partial E(y^* | X) / \partial X_k = \beta_k$, the total marginal effect, $\partial E(y | X) / \partial X_k$ takes into account the fact that a change in an explanatory variable will affect simultaneously the number of participants and the land used for the new technology by both current and new adopters of the technology Wossink and Wenum (2003).

Given the limits of y_i^*, two standard variables can be defined as:

$Z_o = -X_i\beta/\sigma$ and $Z_1 = (1 - X_i\beta)/\sigma$. (4)

It is possible to extend the results of Tobin (1958) and Maddala (1992) to show that the unconditional expected value of the dependent variable, $E(y)$, can be represented as:

$$
\begin{aligned}
E(y) &= Pr(y=0)0 \\
&\quad + Pr(0<y^*<1)E(y \mid 0<y<1) + Pr(y=1)1 \\
&= X_i\beta[F(Z_1) - F(Z_o)] + \sigma[f(Z_o) - f(Z_1)] + [1 - F(Z_1)]. \qquad (5)
\end{aligned}
$$

On the other hand, the expected value conditional upon being between the limits is:

$$
\begin{aligned}
E(y^*) &= E(y \mid X, 0 < y^* < 1) \\
&= X\beta + \sigma\frac{f(Z_o) - f(Z_1)}{F(Z_1) - F(Z_0)}. \qquad (6)
\end{aligned}
$$

Combining equations (5) and (6) it can be derived that:

$E(y) = [F(Z_1) - F(Z_o)]E(y^*) + [1 - F(Z_1)]$, (7)

where $F(Z_1) - F(Z_o)$ is the probability of adopting the new technology (no-till or Roundup Ready soybean). Gould et al. (1989) subsequently notes that from the discussion above the estimated coefficients, β, do not represent the marginal effects of a unit change in the independent variables on $E(y)$ or $E(y^*)$.

By extending the decomposition of the one-limit Tobit suggested by McDonald and Moffit (1980), Gould et. al. (1989), Fernandez-Cornejo and McBride (2002) and most recently Wossink and Wenum (2003) show that:

$$\frac{\partial E(y \mid X)}{\partial X_K} = \xi_0 + \xi_1 + \xi_2, \qquad (8)$$

where,

$$\xi_0 = \left\{ X\beta + \sigma\left[\frac{f(Z_o) - f(Z_1)}{F(Z_1) - F(Z_0)}\right]\right\}.\left[f(Z_o) - f(Z_1)\right].\frac{\beta_k}{\sigma},$$

$$\xi_1 = F(Z_1) - F(Z_0).\beta_k$$
$$.\left\{1 + \frac{Z_o f(Z_o) - Z_1 f(Z_1)}{F(Z_1) - F(Z_0)} + \frac{[f(Z_o) - f(Z_1)]^2}{[F(Z_1) - F(Z_0)]^2}\right\},$$

and

$$\xi_2 = \beta_k\left[\frac{f(-Z_1)}{\sigma}\right].$$

Simplifying equation (8) above, we obtain the total marginal effect as:

$$\xi_T = \frac{\partial E(y/X)}{\partial X_k} = \beta_k.[F(Z_1) - F(Z_0)]. \tag{9}$$

It is therefore obvious from equation (8) that the total effect of a change in an independent variable X_k on the unconditional expected value of the proportion of land used for the new technology can be decomposed into three parts: (a) the change in the probability of adoption (participation in the new technology) weighted by the conditional expected value of the proportion of acreage enrolled, given that the farmer adopts but does not adopt using 100 percent of land, ξ_0; (b) the change in the percentage of acreage used by farmers who are already participating in the adoption of the new technology weighted by the probability of participating, ξ_1; and (c) the change in the probability of fully adopting the technology ξ_2.

6.3 The Simultaneous Adoption of No-till and Roundup Ready Soybeans

Coupling the adoption of no-till planting technology with the adoption of the RR soybean varieties combines the adoption of two technological concepts where on one hand, a new mechanical technology that may modify the crop's interaction with the soil is used and, on the other, the utilization of a herbicide tolerant seed which is resistant to the broad-spectrum herbicide, Roundup Ready with glyphosate. Invariably, this presents the idea of simultaneity between the two technologies. Earlier in our introduction, the question was asked: whether the availability of RR soybean varieties encourages farmers to adopt no-till farming technology for its cultivation and/or vice versa. On the basis of this question, it is our notion that the availability of RR soybeans is likely to affect the farmer's decision to adopt no-till and the adoption of no-till may also impact the decision to use RR soybean seeds. This therefore suggests that the two decisions are endogenous to each other and may be made simultaneously.

I follow the model proposed by Fernandez-Cornejo et al. (2002) however, unlike Fernandez-Cornejo et al. (2002) I include some non-pecuniary factors that affect the simultaneous adoption of agricultural technologies. As discussed in Marra et al. (2004) the role of non-pecuniary factors (such as the value of operator and worker safety, environmental benefits and convenience characteristics of RR soybeans) in the adoption of RR technology and reduced tillage (including no-till) is key to explaining the concomitant nature of this adoption process.

Subsequently, to model this simultaneous adoption decision, I construct a simultaneous, two-equation econometric model, where the equations are binary given that the farmer may adopt the technology or not. The objective in this model is to test the hypothesis of simultaneity between the two decisions and also to identify the factors that account for the simultaneous adoption of the technologies.

6.3.1 Model Specification and Test for Simultaneity

A probit model is used to investigate the adoption decision process. The probit model is described in Madalla (1983, p. 246). By extending a single-equation probit model to a two-equation probit model a two-stage method is first used to estimate the following reduced-form probit models:

$$Y_1{*} = \rho_1^{'} X_i + \mu_1, \quad (1)$$

$$Y_2{*} = \rho_2^{'} X_i + \mu_2. \quad (2)$$

Where X_i is a vector of all the exogenous variables expected to impact the probability to adopt either of the two technologies (such as farmsize, farmyears, education, region, total cost difference, yield difference, value of time spent cultivating RR soybeans, value of market uncertainty, value of equipment savings etc). $Y_1{*}$ is the dependent variable for the probability of adopting no-till and $Y_2{*}$ represents the probability of adopting the Roundup Ready technology. $\rho_1^{'}$ and $\rho_2^{'}$ are the coefficients of the explanatory variables to be estimated.

After estimating equations (1) and (2) separately, the predicted values $Y_1{**}$ and $Y_2{**}$ are retrieved from the two equations respectively and then used to estimate the structural equations below:

$$Y_1{**} = \eta_1^{'} Y_2{**} + \rho_1^{'} X_1 + \nu_1, \quad (3)$$

$$Y_2{**} = \eta_2^{'} Y_1{**} + \rho_2^{'} X_2 + \nu_2, \quad (4)$$

where the predicted values v_1 and v_2 are error terms, Y_1** and Y_2** are considered to be endogenous to each other interchangeably in this second stage of estimation and X_1 and X_2 are the explainatory variables expected to influence the decision to adopt no-till technology and RR soybean technology respectively. However this empirical procedure is difficult to estimate. Hence as explained in Fernandez-Cornenjo et al. (2002), the simultaneous system described above is first estimated after which the two standard, single-equation probit models for the probability of the adoption of no-till and RR soybean technologies were estimated separately to test the simultaneous adoption decision. In each equation I included the adoption of the other technology as one of the explanatory variables. I then used the estimated parameters of the two models (i.e. the single equation and the simultaneous models) to construct a Wu-Hausman test discussed below to test the simultaneity of the two decisions.

6.3.2 *The Wu-Hausman Specification Test*

The Wu-Hausman specification test can be used to test a hypothesis in terms of the bias or inconsistency of an estimator Green (2000, p. 384). Consider a linear regression model $y=X\beta + u$ where y is R x 1, β is a K x 1 vector of parameters, X is an R x K matrix of observations and u is an R x 1 vector of disturbances with mean zero and a covariance matrix of $\sigma^2 \boldsymbol{I}$. In this test if the elements of X are correlated with the error term, then the ordinary least square estimator $\hat{\beta}=(X'X)^{-1}X'y$ is inconsistent. In its specification the null hypothesis of no endogeneity is tested against the alternative that endogeneity is present and the test is conducted by comparing the asymptotically efficient estimator $\hat{\beta}$ to an estimator $\tilde{\beta}$ that is consistent under the alternative hypothesis. It is also assumed that $\hat{\beta}$ and $\tilde{\beta}$ are asymptotically jointly normal under the null hypothesis, H_0. Subsequently, if the difference between the two estimators is given by $\hat{q} = \tilde{\beta} - \hat{\beta}$ and there is no misspecification in the model, then the probability limit difference between the two estimators is zero else it is nonzero. The Wu-Hausman test statistic is therefore given by:

$$m = \hat{q}'[\tilde{V} - \hat{V}]^{-1}\hat{q},$$

where $\tilde{V}$ and $\hat{V}$ are consistent estimates of the asymptotic covariance matrix of $\tilde{\beta}$ and $\hat{\beta}$ respectively. Hausman (1978) shows that under the null when no misspecification is present, the statistic $m = \hat{q}'[\tilde{V} - \hat{V}]^{-1}\hat{q}$, is asymptotically distributed as chi-square with k degrees of freedom. Where k is the number of unknown parameters in β and $[\tilde{V} - \hat{V}]$ is nonsingular with a rank of k.

Using the Wu-Hausman test statistic, I tested the null hypothesis that, the standard probit model that ignores simultaneity or endogeneity is the correct specification against the alternative hypothesis that it is not. The idea here is that if the decision to adopt no-till technology and RR soybean seed varieties is in fact simultaneous, then the estimates from the standard probit equations are inconsistent and the simultaneous model is the preferred model specification and thus will provide a better explanation of the factors that influence the adoption of the two technologies.

Chapter 7

7.1 On the Issue of Complementarity: Verifying a Necessary Condition

Introduction

The goal of this section of the paper is to establish a necessary condition that allows for the verification of the possible complementarity that might exist between the two technologies (no-till and RR technologies) adopted simultaneously.

Although the current study does not necessarily seek to prove unambiguously nor provide all the sufficient conditions needed to establish complementarity, it is hoped that the information gathered from the empirical results will (a) reveal some evidence of the presence or absence of complementarity between the two technologies and (b) provide a better insight on the joint adoption of the two technologies by revealing some drivers of the complementarity, if present. It is hoped that this test will serve as a supportive evidence of complementarity if the technological practices are adopted simultaneously.

I will first provide a brief theoretical background to motivate the idea of complementarity after which I will provide a unified framework for testing for complementarity through the estimation of a reduced form regression. This approach is adopted since it is not easy to investigate comlementarity using structural equations due to inadequate data information (Arora, 1996).

Theory:

The fundamental principles supporting the idea of complementarity between two technological practices rely on the theory of supermodularity. That is, if the function $\pi(A_i, A_j, X)$ is supermodular in A_i, A_j and X, then it implies that the optimal choice decision $A^*(X) = (A_i^*(X), A_j{}^*(X))$, is monotone and non-decreasing in X, where $A_i(X)$ and $A_j(X)$ are complementary activities, and X is a vector of exogenous variables and $\pi(A_i, A_j, X)$ is a performance function. With this assumption, the activities $A_i(X)$ and $A_j(X)$ are considered to be correlated.

To illustrate this idea consider, for example, two practices, y_1= No-till and y_2=RR soybean technology, that can be adopted by a farmer (y_j=1) or not (y_j=0) where $j \in \{1,2\}$. It can be inferred from the theory of supermodularity that the performance function $\pi(y_1, y_2, X)$ is supermodular and y_1 and y_2 are complements if:

$$\pi(1,1) - \pi(0,1) \geq \pi(1,0) - \pi(0,0).$$

In words, adding an activity while already performing the other activity has a higher incremental effect on the performance function $\pi(y_1, y_2, X)$ than when undertaking the activity in isolation. This theoretical result therefore implies that two activities that are complementary will be positively correlated if the performance function is supermodular in the activities and the exogenous variables.

Subsequently for this model, since the use of no-till and roundup ready soybeans farming practices are considered to be complementary activities, it can also be inferred from economic theory that a change in the input price of one (e.g. a decrease in input price of RR soybeans) will have a direct effect on the probability of adoption or use of that technology, which will in turn increase or decrease the probability of adopting the other technology.

Complementarity suggests a positive correlation between the two activities such that corr(y1, y2)>0 and the marginal productivity of y_2 (RR soybean technology) increases with an incremental allocation of land for y_1 (no-till technology) i.e. $\frac{\partial mp_{y_2}}{\partial y_1} > 0$, holds. It is important to emphasize that even though these assumptions are necessary conditions to be met if the two technologies are in fact complementary, they are not necessarily sufficient conditions that will allow the current study to fully establish complementarity conclusively. However, the results above allow us to test some empirical predictions and assumptions made regarding the correlation between the two technologies.

7.2 An Empirical Model for Complementarity

The model uses the direct or productivity approach in which a measure of performance is regressed on the possible technological combinations available to the farmer and the farm and farmer characteristics. Subsequently, we proceed by creating dummy variables that indicate whether a farmer adopted RR or not and whether he used no-till or not. From these variables we construct different exclusive categories for those that used: (i) both RR soybeans and no-till (NT_RR); (ii) No-till only (NTonly); (iii) RR soybeans only (RRonly); and finally (iv) no no-till nor RR soybeans (NRR_NNT) technological practices.

A measure of performance, the performance function is used as the regressant. Subsequently, the variable PYLDDIF (Proportionate yield difference between RR soybean and traditional varieties) was used as the dependent variable, which is regressed on the farm and farmer characteristics and the set of exclusive dummies defined in the regression. PYLDDIF is a good candidate as a measure of the performance of the technological combination adopted because it is a measure of the proportionate increase in the productivity of the new technology relative to the conventional technology (traditional soybean varieties).

Generally, the empirical problem can implicitly be represented as:

$$\pi^{i}(\mathbf{Z}, X_{1}\ldots\ldots\ldots X_{n}; \lambda, \beta),$$

where **Z** is a matrix of mutually exclusive dummy variables indicating how an individual farmer has organized his practices with respect to land allocation to the available technologies. Therefore for the two technologies considered in this model, **Z** ={(0,0),(0,1),(1,0), (1,1)}, and X_i on the other hand is a matrix of control variables for farm and farmer characteristics (including; farmsize, farmyears, education, region, total cost difference, yield difference, value of time spent cultivating RR, value of market uncertainty, value of equipment savings etc.) that affect the innovative performance, λ is a vector of parameters on the dummies **Z**, and finally, β is a vector of parameters on the exogenous variables.

The following equation was then estimated:

$$\Pi^{i}(A_1^i, A_2^i, X_i; \lambda, \beta) = (1-A_1^i)(1-A_2^i)\lambda_{00} + A_1^i(1-A_2^i)\lambda_{10}$$

$$+(1-A_1^i)A_2^i\lambda_{01} + A_1^iA_2^i\lambda_{11} + X_i\beta + \mu_i$$

where for an individual farmer *i*, $A_j^i \in (0,1) \quad \forall j = 1,2$ .This indicates the technology choice[1] of farmer *i*. X_i is a vector of exogenous variables that affect the innovative performance. The λ_{kl} are the coefficients on the technological strategy of choice adopted by the farmer with β being a vector of parameters on the exogenous variables.

[1] No RR and no-till=$(1-A_1^i)(1-A_2^i)$, *notill* only= $A_1^i(1-A_2^i)$, RR only=$(1-A_1^i)A_2^i$, RR and no-till=$A_1^iA_2^i$

7.2.1 *Testing for Complementarity*

As discussed above, one way to test for complementarity is to test whether the choice variables are correlated. The alternative approach is to test by directly testing whether the objective function is supermodular. Therefore, from the definition of supermodularity, the empirical results obtained are used to construct the nontrivial inequality constraint in order to test the condition for complementarity between the two activities no-till (A_1) and RR soybeans technology (A_2):

$$\lambda_{11} - \lambda_{10} \geq \lambda_{01} - \lambda_{00} \text{ or that } \frac{\lambda_{11} - \lambda_{10}}{\lambda_{01} - \lambda_{00}} \geq 1.$$

The equation above intuitively presents the notion that the returns to adopting one practice (RR soybeans) are higher when the other practice (no-till technology) has been adopted. In other words, adding an activity while performing another activity will result in a higher incremental performance than when choosing to engage in the activities separately. Under the assumption that the drivers of the adoption are uncorrelated with the error term μ_i, the proposed test establishes complementarity provided that the estimates of the coefficients λ_{kl} are unbiased. Ichniowski et al. (1997) used a similar restriction to study the effects of human resource management practices on productivity. Finally, an F test was conducted under the null hypothesis of no complementarity against the alternative of the presence of complementarity between the two technologies. A 95% confidence interval was also established for the parameter $\hat{C}$ (i.e. $\hat{C} \pm t^*se(\hat{C})$), Where $\hat{C}$ is a linear function of the estimated parameters of the exclusive dummies thus, $\hat{C} = \lambda_{11} - \lambda_{10} - \lambda_{01} + \lambda_{00} \geq 0$. This is done to further authenticate our results and conclusions about the presence of complementarity. The standard error for the linear combination $\hat{C}$, is calculated by using the results of the variance-covariance matrix obtained from SAS when the COVB option is included in the model statement.

Chapter 8

8.1 Estimation Results and Discussion

Section 8.1 of this paper presents the results of the individual and the concurrent adoption of the agricultural technologies. In the ensuing results, I am interested in observing how the results change or conform to that of other specifications for the adoption of the individual technologies. Subsequently, the results of an alternative model to the FGLS, a two-limit Tobit specification, are also included in the discussion. This will allow for a check on the robustness of our results and also provide information on the extent of adoption of the technologies as I attempt to find the factors that explain the individual adoption of the two technologies, using FGLS (instead of OLS), and the Tobit procedure described earlier.

Consequently, regarding the adoption of the technologies modeled in this study, I first analyze the factors that influence the decision to adopt the technologies individually followed by a discussion of the factors that affect the simultaneous adoption of no-till and RR soybeans. This is done in order to present an in-depth understanding of the possible reasons why farmers may adopt the technologies as a single unit and not as a whole package as encouraged by researchers and also reveal the factors that explain the simultaneous adoption of the technologies.

Finally, I use the identified factors that affect the simultaneous adoption of no-till and RR soybeans to investigate the possibility of the presence of some degree of complementarity between no-till technology and RR soybean technology. The result of the test of a necessary condition for the presence of complementarity is also presented following a discussion of the results of the empirical models of technology adoption.

Table 10. Feasible GLS Results: Adoption of No-till Technology

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	17.27596	6.23249	2.77	0.006**
farm_a02	-5.20201	0.56065	-9.28	<.0001***
farmacsq	1.20306	0.11744	10.24	<.0001***
pctowned	0.00458	0.00504	0.91	0.3649
vtime_rt	0.19503	0.14526	1.34	0.1808
vconv_rt	0.06839	0.02523	2.71	0.0072**
venv_rt	0.46455	0.20106	2.31	0.0218**
rr_p02	0.02786	0.0057	4.88	<.0001***
nt_rt_p01	0.51868	0.02513	20.64	<.0001***
farmyears	1.51021	0.05133	29.42	<.0001***
time_pf	0.00805	0.00857	0.94	0.349
educ	-2.50539	0.89934	-2.79	0.0058***
educ2	0.10237	0.03239	3.16	0.0018***
region	0.57765	0.55441	1.04	0.2986

R^2 = 0.9763
Adjusted R^2 =0.9749
***1% significance level
** 5% significance level
*10% significance level

Concerning the adoption of no-till technology, the empirical results of the FGLS specification model presented in table 10 above reveals that farm size significantly influences the adoption of no-till positively as presumed earlier. This is in consonance with the findings reported by previous studies including Fernandez-Cornejo et al. (2003) and Marra and Carlson (1987) to mention a few. Studies, including the ones mentioned, have shown that farms below a certain critical level in size tend not to adopt new farming technologies, most likely because of the fixed cost of adoption, while larger farms, on the other hand, are more likely to adopt new technologies. Even though the FGLS results indicated that land-ownership is positively related to the adoption of no-till, it did not significantly affect the adoption of no-till.

The estimates also indicate that years of farming experience is significant and positively related to the adoption of no-till technology in both regressions. Furthermore, the adoption of no-till is positively and significantly influenced by the level of education in the FGLS model. In other words, the more educated farmers are, the more likely they are to adopt the new technology. These factors reflect the impact of managerial ability of the farmers on the likelihood of using the new technology. It can be argued that the more experienced and educated the farmer is the more likely he is to understand and appreciate the economic benefits of the new technology (e.g. no-till technology) hence its adoption.

The percentage of land used for reduced till including no-till in 2001 is included in the model as a lagged variable that captures the impact of learning on the adoption of no-till technologies (an attempt to capture the impact of 'learning by doing'-dynamic learning effects). The results show that the lagged variable also significantly affects the adoption of no-till positively. This shows that farmers learn to improve their skill overtime as they adopt the seemingly sophisticated farming technology and this enhances their productivity. The acreage of land used for no-till is also found to be directly related to that used for RR soybeans when no-till is adopted. Though not significant, the explanatory variable for time spent doing off-farming activities, has the expected sign and has a positive relationship with the acreage of land under no-till technology. The dummy variable 'region' has no significant effect on the adoption of no-till technology in the FGLS model.

The estimated results obtained from the FGLS model show that the role of some non-pecuniary factors cannot be ignored. Our results reveal that in the FGLS model, the value of convenience factors and value per acre of an additional environmental benefit from adopting reduced till (including no-till) were positively associated with the adoption of no-till technology at the 5% and 10% level of significance. However, the value of per acre time-savings was not significant in this regression even though it had the expected positive sign.

Table 11. Estimated Tobit Coefficients Showing Marginal Effects and Decomposition

(Dependent Variable: Proportion of No-till Planted Acreage) Total Decomposition

Parameter	Estimate	Standard Error	Square	Pr>ChiSq	ξ_T	ξ_0	ξ_1	ξ_2
Intercept	1.8582	0.5537	11.26	0.0008***				
farm_a02	1.9148	0.3297	33.73	<.0001***	0.557998	0.033331	0.51669	0.007971
farmacsq	-0.0286	0.0288	0.99	0.3207	-0.00833	-0.0005	-0.0077	-0.00012
pctowned	-0.0019	0.0024	0.63	0.4289	-0.00055	-3.3E-05	-0.0005	-7.9E-06
vtime_rt	0.0056	0.0118	0.22	0.6372	0.00163	9.7E-05	0.00151	2.3E-05
vconv_rt	0.036	0.014	6.61	0.0102***	0.010491	0.00063	0.00971	0.00015
venv_rt	0.0123	0.0184	0.44	0.5059	0.003584	0.00021	0.00332	5.12E-05
rr_p02	0.0101	0.0026	15.15	<.0001***	0.002943	0.00018	0.00273	4.2E-05
tot_nt_p01	0.2356	0.0377	39.09	<.0001***	0.068657	0.00410	0.06358	0.00098
farmyears	0.9353	0.071	173.51	<.0001***	0.272559	0.01628	0.25238	0.00389
time_pf	0.0129	0.0041	9.67	0.0019***	0.003759	0.00023	0.00348	5.37E-05
educ	3.2188	0.2624	150.51	<.0001***	0.938001	0.05603	0.86857	0.01339
educ2	-0.0073	0.0017	18	<.0001***	-0.00213	-0.00013	-0.0019	-3E-05
region	12.6285	1.8562	46.29	<.0001***	3.680111	0.21983	3.40772	0.05257

***1%, **5%, *10% Level of significance, Log Likelihood = -218.6580387.

ξ_0, ξ_1, ξ_0, represent the elasticities of change in the independent variables on the adoption and use of no-till for those who do not currently use the technology, those who currently use the technology and in the total use of no-till. ξ_T is the total effect of a change in an independent variable on the proportion of acreage cultivated with new technology.

Table 11 presents the estimated Tobit coefficients obtained from the Tobit regression that was conducted to determine the effect of the explanatory variables on the adoption and the intensity of adoption of no-till farming technology. The dependent variable as it were, is the proportion of land used for no-till technology. On average the results of our two-limit Tobit model is similar to that of the FGLS and had the expected signs. Considering the individual variables, it can be seen that farm size significantly affected the enrollment of land parcels into the conservation program (i.e. no-till) in a positive way, while the percentage of land owned did not significantly affect the adoption of the new technology. Although the value of time savings from engaging in no-till farming and the value of environmental safety were not found to have significant impact on the adoption of no-till, the value of convenience factors associated with the use of no-till technology was found to have a positive impact on no-till adoption at the 1% level of significance. As hypothesized earlier, the proportion of land used for Roundup Ready soybean technology was found to have a significantly positive effect on the proportion of acreage used for no-till. Again, revealing the positive correlation between the two technologies. Furthermore, as found in the FGLS specification, we found evidence of 'learning by doing' since the lagged variable of our dependent variable had a positive impact on the proportion of acreages used for no-till in 2002. This variable was found to be significant at the 1% level. It was also found that the older and more experienced farmers were the more likely they were to use no-till. Moreover the level of education also had a positive impact on the adoption of no-till at the 1% level. Here again supporting the fact a higher level of education enhances the farmer's managerial skills through enhanced ability to obtain, process and use information pertaining to the use of the new technology. The variable for the percentage of time spent doing off-farm activities also had a significantly positive impact on the adoption of no-till. This is not surprising though since farmers who have other off-farm employment will seek to engage in less time consuming farming activities in order to save time for their off-farm engagements. The positive and significant regional dummy variable in the Tobit model also suggests that farmers in the Midwest were more likely to enroll more parcels of land into new farming technology.

With respect to the intensity of adoption, we calculated the total marginal effect and the subsequent decomposition based on the estimated coefficients of our model. It is also important to note that the elasticity of changes in the independent variables on the adoption of no-till is calculated at the means of the variables. Table 11 thus presents the total marginal effects and the decomposition for farmers who currently do not use no-till (ξ_0); for those who currently use no-till but enrolled less than 100 percent of total acreage (ξ_1); and those who enrolled their total acreage of land into no-till farming (ξ_2).

From the calculated marginal effects it implies that an extra increase or 1 percent increase in farm size will increase the proportion of land used for no-till by 55 percent while an incremental amount in the value of convenience factors would increase the intensity of adoption of no-till by 1.1 percent. On the other hand a unit increase in the years of farming would increase the intensity of adoption by 27 percent and a similar increase in the level of education interestingly increases the intensity of adoption by 93 percent. Interpreting the elasticities we can for example infer that, for a 1 percent increase in farm size, the proportion of planted acreage under no-till would increase by 0.8 percent, the probability of current non-users adopting no-till would increase by 3.3 percent and there would be a 51 percent increase in the proportion of planted acreage under no-till by those who are currently using the new conservation tillage technology. In general, however, the marginal effects of farmers who would use 100 percent their land for no-till, is relatively smaller than those currently using less than 100 percent of their land for no-till but would increase their acreages for a marginal increase in an explanatory variable.

Table 12. Feasible GLS Results: Adoption of Roundup Ready Soybean Technology

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	-0.16795	0.09666	-1.74	0.0875
farm_a02	0.00001289	0.00010249	0.13	0.9003
farmacsq	9.73E-09	3.01E-08	0.32	0.7476
nt_rt_p02	0.00559	0.00164	3.4	0.0012***
pctowned	0.00007579	0.00064763	0.12	0.9072
tcostdif	-0.01754	0.00708	-2.48	0.0161**
vtime_rr	0.00283	0.00431	0.66	0.5142
vhumenv	0.60013	0.25111	2.39	0.0201**
vuncseed	-0.0000945	0.00274	-0.03	0.9726
rr_p01	0.12552	0.14772	0.85	0.3989
ylddif	1.35836	0.53126	2.56	0.0132**
farmyears	0.39377	0.18949	2.08	0.0421*
time_pf	1.09121	0.13426	8.13	<.0001***
educ	-14.9939	2.59374	-5.78	<.0001***
educ2	0.67435	0.10401	6.48	<.0001***
region	18.07877	8.60946	2.1	0.0400*

***1% significance level

** 5% significance level

*10% significance level

$R^2 = 0.9824$

Adjusted $R^2 = 0.9779$

From table 12 it is obvious that overall, the factors that influence the adoption of RR soybean technology considered here had the appropriate expected signs. It is quite obvious from the results of the FGLS analysis that the effect of farm size on the adoption of RR soybean technology is not statistically significant. This seems to indicate that the adoption of RR soybeans unlike the adoption of no-till technology is likely to be neutral to farm size. A possible explanation has been offered that since genetically engineered crop technologies can easily be incorporated into current production technologies, it is likely to be invariant to farm size as opposed to the adoption of no-till which may require substantial human and financial capital and is therefore more likely to be adopted on larger farms (Price et. al, 2003). Ownership of land, the value of time saved in planting RR soybeans, the percentage of acreage planted to RR soybeans in the previous year (2001) all had a positive impact on the adoption of RR soybeans but were not statistically significant. With respect to the value of market uncertainty in planting RR soybeans, I found that it had a negative impact on the adoption of RR soybeans though not statistically significant also. This implies that farmers were quite skeptical about the consumer's acceptance of RR soybeans and were possibly concerned about the debate on the ethical issues surrounding the production and consumption of RR soybeans.

On the other hand, the percentage of land used for no-till positively influenced the decision to adopt RR soybeans technology and was significant at the 1% level in the FGLS specification. This seems to suggest some positive correlation between the adoption of the two technologies as proposed. This will be verified in the simultaneous adoption model in the next section of the study.

As inferred by many studies, the comparative cost advantage of RR soybean varieties over the conventional soybeans varieties also enhances the adoption of RR soybeans. It was found that the higher the cost difference between RR soybeans and the conventional soybean varieties the less likely farmers were to adopt the RR soybean technology. This negative relationship was statistically significant at the 5% level of significance.

The difference in yield between the RR soybean and the traditional soybean varieties is also found to have a positive impact on RR soybean adoption and is statistically significant at the 5% level in the FGLS analysis. Hence the higher the yield difference, the more likely farmers were to increase their Roundup ready soybean acreages. The years of farming experience positively affected the adoption of RR and was statistically significant at the 10% level while the percentage of time spent engaging in off-farm labor and the level of education were also positively related to the adoption of RR soybean technology but significant at the 1% level. Finally, the dummy variable for region was also significant at the 10% level and the estimated parameter had a positive sign indicating that farmers in the mid-west were on average more like to adopt RR soybeans as opposed to their counterparts in the south. This inference might not necessarily be the case since information from the survey shows that there were more responses from farmers in the mid-west than those in the south.

Table 13. Estimated Tobit Coefficients Showing Marginal Effects and Decomposition

(Dependent Variable: Proportion of RR Planted Acreage) Total Decomposition

Parameter	Estimate	Standard Error	Square	Pr>ChiSq	ξ_T	ξ_0	ξ_1	ξ_2
Intercept	2.54	0.6676	14.48	0.0001***				
farmsize	-2.1128	0.4183	25.51	<.0001***	-1.370	-0.148	-1.222	-0.00013
farmsizesq	0.878	0.1591	30.44	<.0001***	0.569	0.062	0.508	5.52E-05
nt_rt_p02	1.7304	0.0966	321	<.0001***	1.122	0.121	1.00083	0.000109
pctowned	-0.089	0.0548	2.64	0.1044	-0.058	-0.0062	-0.0515	-5.6E-06
tcostdif	-1.251	0.2111	35.13	<.0001***	-0.811	-0.088	-0.724	-7.9E-05
vtime_rr	0.0015	0.0132	0.01	0.9079	0.00097	0.00011	0.00087	9.43E-08
vhumenv	0.328	0.3091	1.13	0.2886	0.213	0.023	0.1897	2.06E-05
vuncseed	-0.1681	0.1357	1.54	0.2152	-0.109	-0.012	-0.0972	-1.1E-05
rrpct_01	0.414	0.2238	3.42	0.0644*	0.269	0.029	0.239	2.6E-05
ylddif	0.8164	0.2513	10.56	0.0012***	0.529	0.057	0.472	5.1E-05
farmyears	0.2512	0.0975	6.64	0.01***	0.163	0.018	0.1453	1.58E-05
time_pf	0.0103	0.0037	7.62	0.0058***	0.0067	0.0007	0.0059	6.5E-07
educ	0.0084	0.0268	0.1	0.7542	0.0055	0.00059	0.0049	5.28E-07
educ2	-0.0668	0.0231	8.36	0.0038***	-0.043	-0.0047	-0.039	-4.2E-06
region	0.5681	0.1695	11.23	0.0008***	0.369	0.0399	0.329	3.6E-05

***1% **5% *10% Level of Significance, Log Likelihood= -16.17339236

The results of the estimated Tobit coefficients for the adoption of Roundup Ready soybean technology are presented in table 13. The dependent variable in this Tobit regression is the proportion of land used for cultivating Roundup Ready soybeans. Of the explanatory variables included in this model the value of time saved, the value of human and environmental safety from using Roundup Ready soybeans, the value of market uncertainty and the percentage of acreage owned were not significant factors in explaining the adoption of the new technology.

However, farm size was not only found to influence the adoption of Roundup Ready soybeans positively at the 1% level of significance. Our results also reveal that there is a significantly positive relationship between the acreage used for Roundup Ready soybeans and that for no-till technology in 2002 as found in the FGLS model. Farm size and the percentage of land used for Roundup Ready soybeans in 2001 have a positive impact on the adoption of Roundup Ready soybeans at the 1% and 10% significance level respectively. The later provides evidence of 'learning by doing' in the use of Roundup Ready soybeans by farmers. The variable for the difference in yield between Roundup Ready soybean varieties and the traditional varieties had a significantly positive impact on the adoption of Roundup Ready soybeans. Therefore the higher the yield difference, the more likely farmers were to increase the Roundup Ready soybean acreage. As hypothesized, the total cost difference between the cultivation of Roundup Ready soybeans varieties and the traditional soybean varieties had a negative impact on the adoption of Roundup Ready soybeans at the 1% level of significance. Older and more experienced farmers were more likely to increase their Roundup Ready soybean acreages as opposed to younger farmers. The regional dummy variable also had a positive impact on the adoption of Roundup Ready soybeans. This implies that farmers in the Midwest are more likely to increase their Roundup Ready soybean acreages compared to their counterparts in the south. Finally, the level of education has a significantly positive relationship with the adoption of Roundup Ready soybeans.

On the intensity of adoption of Roundup Ready soybeans, we present in table 13 the total marginal effects and the decomposition for farmers who currently do not cultivate Roundup Ready soybeans (ξ_0); for those who currently cultivate less than 100 percent of total acreage with Roundup Ready soybeans (ξ_1); and those who used their total acreage of land for Roundup Ready soybean cultivation (ξ_2). As it was with the adoption no-till technology we observe that in general, the marginal effects of who would use the total acreage of land for Roundup Ready soybeans is smaller than those who will convert an additional portion (but not 100%) of their acreage to Roundup Ready soybean cultivation. Our results also show that an extra increase in total cost difference will decrease the portion of land allocated for Roundup Ready soybeans by 81 percent while an increase in yield difference will increase the Roundup Ready acreage by 52 percent. Interestingly, it is also observed that a marginal increase in no-till acreage would increase the portion of land used for Roundup Ready by more than 100 percent. A unit increase in the years of farming would also result in a 16 percent increase in the total acreage enrolled into the cultivation of Roundup Ready soybeans. From our calculated marginal effects it follows for example, that for a 1 percent increase in total cost difference the proportion of Roundup Ready planted acreage would decrease by 72 percent for those who are cultivating less than 100 percent of their land with Roundup Ready soybeans.

A unit increase in yield difference on the other hand would increase the acreage under Roundup ready soybean cultivation by 5.1×10^{-5} percent. The probability of current non-users of Roundup Ready soybeans adopting the new technology would increase by 5.7 percent and there would be a 47 percent increase in the proportion of planted acreage under Roundup Ready soybeans by current users.

Table 14a. Nonlinear OLS Parameter Estimates Results: No-till Adoption (Simultaneous Equation Model)

Parameter	Estimate	Std Err	t Value	Pr > |t|
rr_adopt_02	0.009939	0.00328	3.03	0.0026***
farm_a02	0.005734	0.00307	1.87	0.0626*
farmacsq	-0.00089	0.000649	-1.37	0.1731
pctowned	0.001931	0.000726	2.66	0.0083**
vtime_rt	0.004667	0.00286	1.63	0.1039
vconv_rt	0.00473	0.00285	1.66	0.0986*
venv_rt	0.000143	0.000102	1.41	0.1603
nt_rt_p01	0.000282	0.00232	0.12	0.9035
farmyears	0.000919	0.00187	0.49	0.6238
time_pf	0.000081	0.000047	1.72	0.0857*
educ	0.046338	0.00841	5.51	<.0001***
educ2	-0.00004	0.000019	-2.33	0.0206*
region	-0.44649	0.094	-4.75	<.0001***

R^2 =0.2082
Adjusted R^2 = 0.1745
* **1% significance level
**5% significance level
*10% significance level

Table 14b. Nonlinear OLS Parameter Estimates Results: RR Technology Adoption (Simultaneous Equation Model)

Parameter	Estimate	Std Err	t Value	Pr > |t|
nt_rt_adopt02	0.010052	0.00196	5.12	<.0001***
tcostdif	-0.01044	0.00109	-9.62	<.0001***
rrpct_01	0.523632	0.0402	13.02	<.0001***
farm_a02	0.030171	0.017	1.78	0.0769*
pctowned	0.000323	0.000468	0.69	0.4906
vtime_rr	0.002164	0.00227	0.95	0.3422
vhumenv	0.000118	0.000112	1.06	0.2913
ylddif	0.02024	0.00425	4.76	<.0001***
vuncseed	-0.00182	0.00205	-0.89	0.3759
farmyears	0.000753	0.00116	0.65	0.5166
time_pf	0.003135	0.000732	4.29	<.0001***
educ	0.010209	0.0053	1.93	0.0552*
region	0.054551	0.0642	0.85	0.3963

$R^2 = 0.8353$
Adjusted $R^2 = 0.8283$
***1% significance level
** 5% significance level
*10% significance level

Table 14c. Results of the Test for Simultaneous Adoption

Simultaneous Adoption Test Result:

	No-Till(T1)	RR(T2)
Chi-Square values d.f.=13	42.023747	89.336187

Tables 14a-c present the results of the simultaneous adoption model. Here again, farm size is found to be positively related to the adoption of both no-till technology and RR soybean technology at the 10% level of significance. This implies that larger farms making this simultaneous decision are more likely to adopt the new technologies in spite of the initial investment cost in seeds, equipment and technology fees. It is also evident that the estimated coefficients of the value of the convenience factors had a direct and significant impact on the adoption of no-till. However, the value of time saved and the value of human safety and environmental benefits did not have a significant impact on the adoption of no-till nor RR soybean technology even though they all had the expected positive sign. This indicates that farmers are conscious and care about the environment and its possible deterioration as well as the safety of the health of their workers. When asked whether there were any human and environmental benefits of using the technologies about 71% of the adopters replied "Yes;" an equal percentage were willing to place a dollar value on the benefits. The value of market uncertainty also had the expected negative sign though not significant as well. This implies that farmers place a negative value on additional market risk that may result from the use of Roundup Ready soybeans possibly because of ethical issues surrounding the use and production of RR soybeans coupled with the fact that they cannot save up seeds from their stock (harvest) for replanting or sale.

The yield difference between RR technology and the non-RR soybean varieties was significant at the 1% level in the simultaneous adoption model unlike the single adoption model where it was not as significant. It is also seen that the yield difference has a positive impact on the adoption of the new seed technology. The greater the difference in yield between RR technology and the non-RR soybean varieties the more likely farmers were to adopt the new seed technology. It is however not surprising that it was not as significant in the single adoption model since very few respondents cooperated on revealing this difference.

The results further show that the percentage of land owned by farmers enhanced the adoption of both RR soybeans and no-till technologies positively. Although this positive effect was apparent for the two technologies, whereas the impact of land ownership had a significant effect on the adoption of no-till it was not statistically significant with regard to its effect on the adoption of RR soybeans. In general, the number of years of farming experience had a positive but insignificant effect on the adoption of both technologies. This could probably be due to the fact that farmers being introduced to the dual components of this new farming technique were all novices at the time of questioning. On the other hand, the level of education was not only positively correlated with the adoption of the new technologies, its impact was significant at the 1% level for the adoption of no-till and the 10% level for the adoption of RR soybean technology. This conforms to the findings of many studies which have concluded that the more educated the farmer is the greater the probability that he will adopt a new technology since he is able to understand the economic benefits of the technology better and earlier than the less educated who tend to be laggards. Thus the level of education is important in explaining the adoption of the two new technologies. The regional dummy included in the model was also statistically significant for the adoption of no-till but insignificant for RR soybean adoption. This is quite inconsistent with the results of the adoption of the technologies as single or individual technologies where the regional dummy was significant in the adoption of RR soybean technology not no-till. Finally, in this simultaneous model, the time spent in off-farm activities is found to be positively correlated with the adoption of the two technologies. This is quite reasonable due to the compatibility of the timing of farming activities in the two technologies. It seems to suggest that adopting no-till and RR soybean technologies together creates a convenience for farmers regarding weed control and tillage activities thus allowing farmers the opportunity to engage in other off-farm activities.

With reference to the simultaneity between the two decisions, after using the SAS program to estimate the coefficients of the parameters in the simultaneous model and the single standard probit models and retrieving the variance covariance estimates for the models, I compared the results and computed the Wu-Hausman test statistic as discussed earlier. In the single equation probit models, the parameters generally did not have the expected signs and were not significant unlike the results of the simultaneous adoption model. The interaction between the adoption of no-till and RR soybean technologies were however found to be positive and significant in the simultaneous model. In other words, the adoption of no-till was a significant explanatory factor the adoption of RR soybeans and *vice-versa*. This result therefore supports the inference drawn from evaluating the two Wu-Hausman test statistics for the decision to adopt no-till and RR soybean technology.

After calculating the test statistic under the null hypothesis that the two standard probit models instead of the simultaneous model is the correct model specification, I computed a chi-square statistic (χ^2, d.f.=13) of 42.02 for the no-till model, and 89.3 for the adoption of RR soybeans model. Hence I reject the null hypothesis that the two standard probit models instead of the simultaneous model is the correct model specification in favor of the alternative hypothesis that the simultaneous model is the most preferable model and hence we conclude that we cannot ignore the simultaneity between the two decisions. This inference is partially shared by Price et al. (2003) except that they found that accounting for simultaneity is necessary for the adoption of no-till but not for the decision to adopt RR soybean technology. Subsequently as anticipated by Price et al. (2003), it seems that RR soybeans is gaining some acceptance through the extensive commercialization by agronomists and Monsanto and the convenience of using no-till with this seed technology is also enhancing the simultaneous adoption of the two technologies.

In conclusion these results reveal that farmers who adopted no-till were more likely to adopt the use of RR soybean technology as well and conversely, the probability of adopting RR significantly influenced the probability of adopting no-till. This implies that cultivation without tillage (no-till) could make the land prone to weed infestation, and farmers using no-till technology found the need to adopt RR soybean technology as a means to control weed infestation. Therefore it is also not surprising that farmers who decide to use RR soybeans prefer to adopt the use of no-till technology. The possible explanation for this phenomenon could stem from the fact that the characteristics of no-till farming create some convenience with RR soybeans for farmers compared to the other conventional tillage practices. No-till allows for less tillage time and fewer passes on a given plot and thus may save farmers some time and money. It could also be that the aggressive commercialization of RR soybeans has encouraged the use of no-till technology.

It is therefore concluded that ignoring the simultaneous nature of the decision to use no-till and RR soybean technologies could lead to the mis-specification of the model and hence our ability to reveal and understand the factors that influence the concomitant adoption of these technologies will be obscured by the inconsistent estimates that will result.

Our investigation into the possible complementarity between the two technologies reveals some evidence of the presence of complementarity though not conclusively. This inference is drawn from the results reported in table 14d below, which is based on our discussion of the empirical test for complementarity in section 7.2 of this dissertation.

Table 14d. F Test: Results for Complementarity

Source	DF	Mean Square	F Value	Pr > F
Numerator	1	705.03711	3.72	0.0544
Denominator	419	189.45670		

As stated earlier, one of the major objectives of this study has been to establish a necessary condition for the presence of complementarity. The results above show that, under the null hypothesis that there is no complementarity between the two technologies, we find that the F value of 3.72 rejects the null hypothesis in favor of the alternative hypothesis. Hence we infer that there is the likelihood of the presence of complementarity between no-till and Roundup ready technologies. Furthermore, our results on complementarity using the direct test approach, is supported by evidence from the calculated 95% confidence interval for $\hat{C}$ which is the linear function of the estimated parameters of the exclusive dummies. Referring to appendix D and subsequently constructing a 95% confidence interval, the value of the linear combination of the estimated parameters of the exclusive dummies $\hat{C}$ is found to be within 0.03 to 0.16. This suggests that we can be 95% confident that the true mean of the value of the linear combination of the estimated parameters falls between 0.03 and 0.16. Hence $\hat{C}$ is likely to be positive. Thus, this finding though not sufficient to fully verify the presence or absence of complementarity, supports the evidence provided by Marra et al. (2004) who reported in their paper that growing Roundup Ready soybeans is complementary to and associated with an increase in the rate of reduced tillage (including no-till) adoption.

Chapter 9

9.1 Market Impact of Adopting RR Soybean Technology

9.1.1 *Introduction*

It is a well-established fact that improvements in technology have the potential to increase productivity, raise real incomes and thus enhance economic growth. In other words, new technologies are expected to allow farmers to do more with less. Subsequently, in this section it is my interest to use a logical economic principle to investigate the possible benefits that producers and consumers have gained as a result of the adoption of RR technology discussed in the earlier chapters of this study.

This chapter therefore consists of a presentation of the welfare model used for the evaluation of the economic benefits from the adoption of new technologies. However, although welfare analysis usually concentrates on policy recommendations, the purpose of the current study is to exploit it as a tool to determine the economic impact of the adoption of a new soybean technology (Roundup Ready soybeans) on the economic gains to producers and consumers in the market.

Therefore, in this section, I will use the graphical approach to illustrate the benefits of adopting No-till technology and RR technology. The analysis will show the welfare benefits gained by producers and consumers, from a technology-induced supply shift. The case of a parallel supply shift due to the adoption of the new innovation and that of a pivotal shift will thus be considered.

9.1.2 *Technology Adoption Impact Assessment Methods*

The methods of assessing the economic impact of a new technology can generally be grouped into two categories: (a) ex-post studies, for technologies being used already, and (b) ex-ante studies, for technologies not yet adopted. Even though, in both cases, some of the data required to measure economic impact can be directly observed, and others ought to be estimated indirectly from other sources, researchers have argued that the ex-post analysis in which actual surveys are used can be more reliable than ex-ante studies, which rely on researchers' trials and extrapolations.

A number of methods can be used to do impact assessment analysis. This includes the econometric approach, which aims at estimating the marginal productivity of the new technology; programming methods, aimed at identifying one or more optimal technologies from a set of activities; and the economic surplus method, which involves the measuring of social benefits from the adoption of new technologies. All three approaches are used quite often. However, in spite of their widespread use, the economic surplus method is the most popular method. This approach has been found to be very applicable to a broad range of situations and requires the least data. Given that it is relatively easy to use and its ability to yield very reliable results, the economic surplus method will be used in the current study.

9.1.3 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.

9.1.4 *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 I 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.

9.2 *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.

Mathematically, the initial linear supply curve is given by:

$$Q^s = \alpha + \beta P, \qquad (1)$$

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:

$$Q^d = \mu + \gamma P, \qquad (2)$$

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.

9.2.1 *Functional Forms of Supply and Demand*

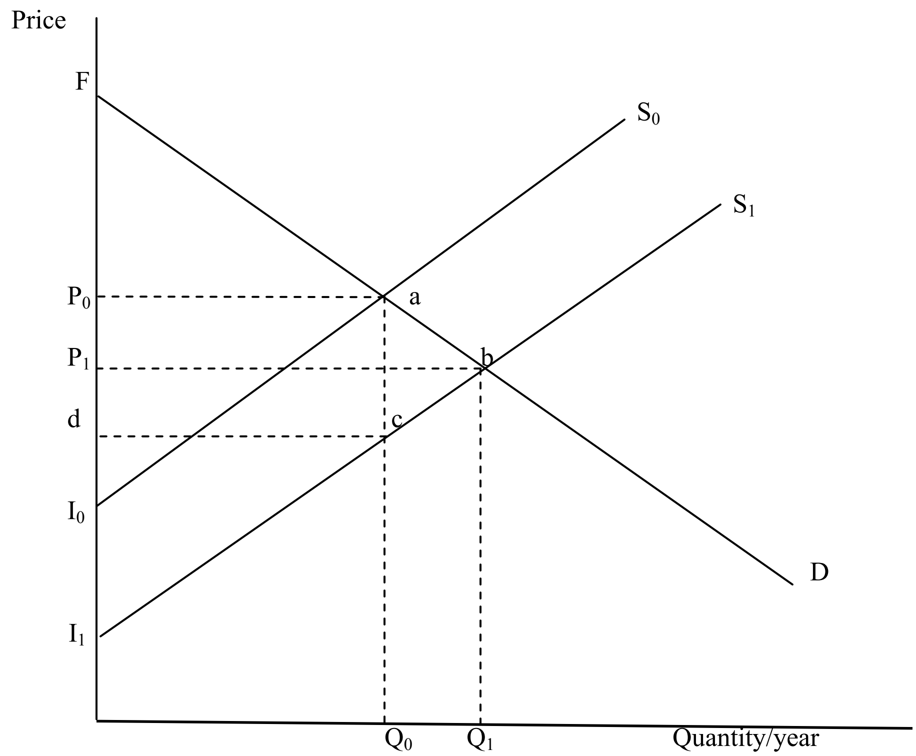
Researchers commonly use the linear and the constant elasticity supply and demand curves in the estimation of research benefits. Others have also suggested the use of kinked supply curves to avoid the erroneous inference that there could be a positive supply at negative prices for a situation where supply 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).

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

In figure 7a 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.

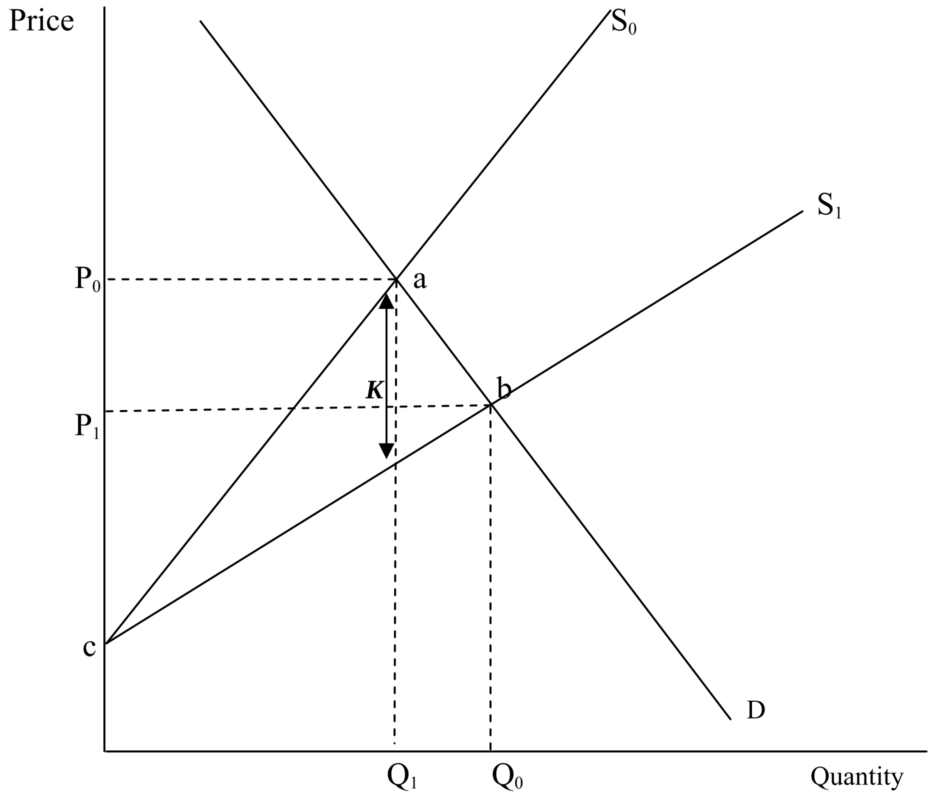
Figure 7a: The Distribution of Welfare Benefits for a Parallel Supply Shift



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 8b) 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 7b. The Distribution of Welfare Benefits for a Pivotal or Proportional Supply Shift



With reference to the discussion in the earlier paragraph, figure 7b 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:

$$P^* = (\mu - \alpha)/(\beta + \gamma) \qquad \text{when } k=0 \tag{7}$$

and

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

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

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

Converting the slopes in equation (9) into elasticities[2], the equilibrium market price that results when the new technology is adopted is:

$$P^{r*}=P_0\{1-(K\varepsilon)/(\varepsilon+\eta)\}, \tag{10}$$

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:

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

$Z = -(P_1-P_0)/P_0 = (K\varepsilon)/(\varepsilon+\eta)$

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:

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

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

The gains in the consumer surplus can therefore be derived and expressed algebraically as:

$$\Delta CS = (P_0 - P_1^{r*})[Q_0 + 0.5(Q_1^{r*} - Q_0)], \quad (13)$$

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

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

[3].

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:

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

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

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

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

[3] A reference to Alston et al., 1995, p. 211 also shows that the expression $(k + P_1^{r*} - P_0)$ is equivalent to $(P_1\text{-}d)$ in the figure 7a above.

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:

$$\Delta TS = 0.5 P_0 Q_0 K(1 + Z\eta]^{4}, \tag{18}$$

and

$$\Delta CS = P_0 Q_0 Z(1 + 0.5 Z\eta]^{5}. \tag{19}$$

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

$$\Delta PS = \Delta TS - \Delta CS\ , \tag{20}$$

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).

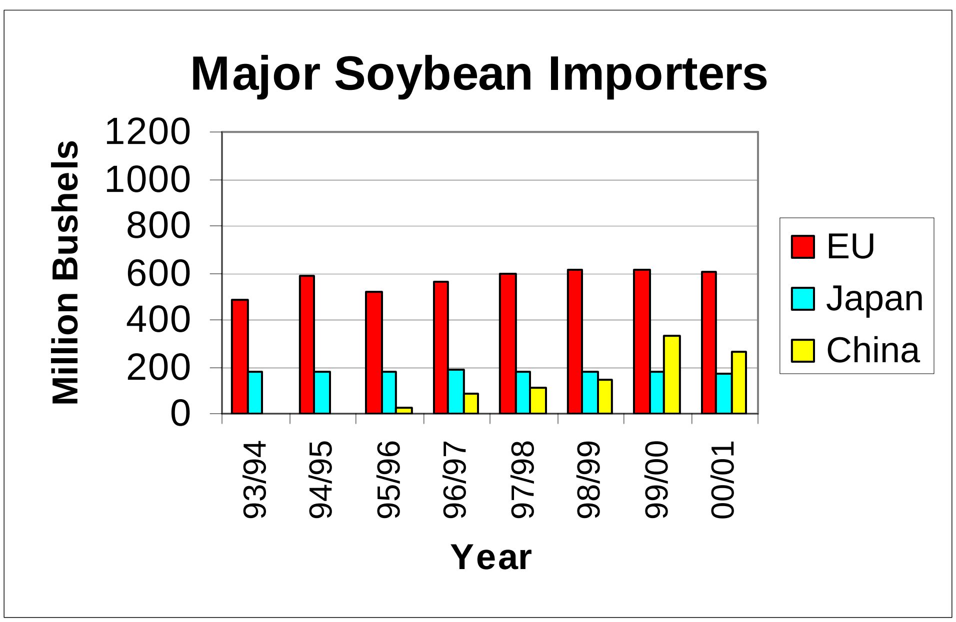
[4] See Lindner and Jarrett, 1978 for proof of formulae.
Equation (18) is true compared to the Ulrich, Furtan and Schmitz (1986) formula on page 108, provided $A_0=A_1$ in the later for a pivotal shift of the supply curve.

[5] Refer to footnote 3 above.

9.4 *The Role of International Trade in the U.S. Soybean Market*

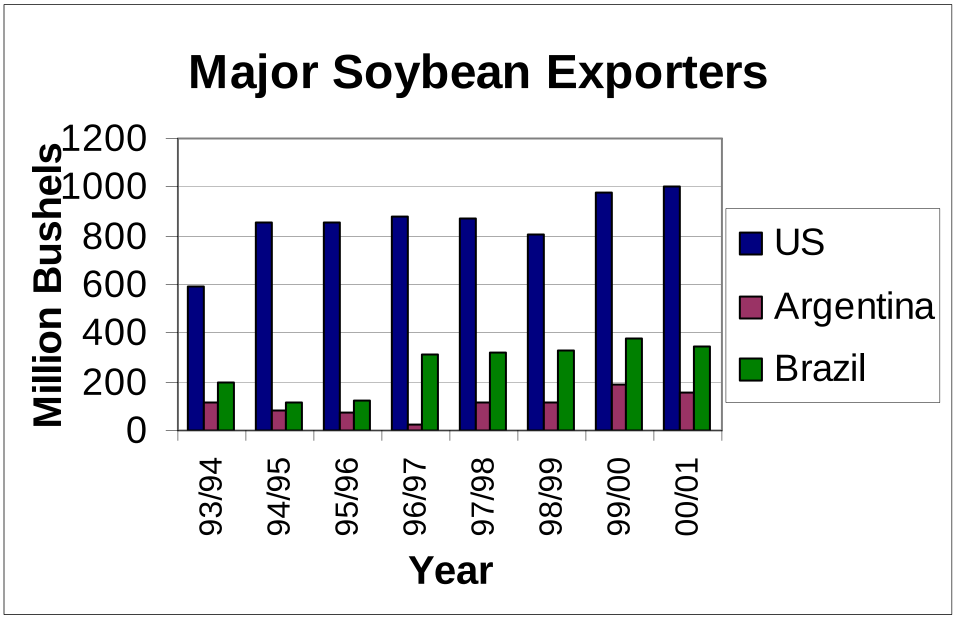
The figure 8a below shows a bar chart of the major soybean importing countries in the world soybean market. It is quite obvious that the market for soybeans has developed quite extensively and the demand for soybean by the European Union (EU), China and Japan is also unequivocally substantial. It can be seen that on average soybean imports to the Rest of the World (EU, Japan, China) exceeded 300 million bushels between the period 1993-2001 with imports by EU being over 500 million on average. It is therefore not surprising that researchers consider international trade as an intrinsic characteristic of the soybean industry and hence argue that it cannot be neglected when analyzing the market impact of the technological changes in the soybean market.

Figure 8a. U.S. Soybean Importers



Source: USDA

Figure 8b. Soybean Exporters



Source: USDA

Also from figure 8b above, it can be inferred that extensive trade undoubtedly characterizes the U.S. soybean market. In spite of the competing exports of soybean from countries such as Argentina and Brazil, figure 8b shows that for the period between 1993 and 2001, U.S. soybean exports were greater than the average production of the other two countries combined by more than a third. Table 15 below provides a catalogue of the numerous trading partners of the U.S. soybean industry. Evidently, not only is the U.S. soybean exports relatively greater compared to the other exporting countries, the number of countries the U.S. exports soybean to is considerably large; including the EU, Asia, Latin America, Africa and the Middle East. This therefore supports the overwhelming evidence of the need to extend the current research study to include the impact of technological changes in the U.S. soybean industry on the Rest of the World (ROW).

Table 15. U.S. Exports of Soybeans and Trading Partners (1999-2000)

	JULY 1999	JULY 2000	SEPTEMBER-JULY 1998/99	SEPTEMBER-JULY 1999/2000
		METRIC TONS		
CANADA	17,231	9,273	197,791	330,123
EUROPE	9,411	18,652	5,392,883	5,974,767
EUROPEAN UNION	9,411	18,652	5,362,961	5,961,101
BELGIUM-LUXEMBOURG	1,279	0	300,971	532,894
DENMARK	0	0	19,015	0
FRANCE	0	0	222,937	138,867
GERMANY	18	0	892,819	703,485
GREECE	0	0	126,263	89,459
ITALY	0	19	228,623	250,563
NETHERLANDS	6,614	953	1,824,840	2,287,873
PORTUGAL	0	0	150,789	224,291
SPAIN	0	0	1,223,528	1,249,799
UNITED KINGDOM	1,500	0	318,555	400,711
NON EU WESTERN EUROPE	0	0	13,814	9,536
EASTERN EUROPE	0	0	16,108	4,130
ASIA (LESS MIDDLE EAST)	527,842	756,361	9,353,275	12,530,817
INDONESIA	39,899	103,860	839,555	934,692
JAPAN	228,702	229,889	3,440,260	3,402,364
KOREA, REP. OF	72,852	13,824	1,113,227	1,246,603
TAIWAN	125,895	105,966	1,761,928	1,894,394
CHINA	69	286,034	1,251,893	3,968,291
LATIN AMERICA	221,746	426,496	3,277,215	3,632,585
MEXICO	193,144	382,053	2,886,471	3,177,205
BRAZIL	0	0	29,628	0
COSTA RICA	10,605	16,503	145,796	167,799
COLOMBIA	13,129	15,330	68,381	93,991
VENEZUELA	0	0	68,419	94,045
AFRICA & MIDDLE EAST	104,760	76,474	794,980	954,807
ISRAEL	51,017	36,385	441,981	477,287
OCEANIA	9,160	0	32,360	8,843
FORMER SOVIET UNION	65,901	6,693	167,666	39,480
CANADIAN TRANSSHIPMENTS	42,262	74,345	1,117,292	1,429,814
TOTAL WORLD	998,313	1,368,294	20,333,462	24,901,236

SOURCE: SEPTEMBER 2000 U.S. BUREAU OF THE CENSUS DATA.

There is therefore ample evidence in support of the fact that U.S. soybean production and processing form a major component of the global soybean sector. For example, in 1997, about 2.7 billion bushels of soybean was produced in the U.S., which was about 47% of the world's production. In fact the American Soybean Association reported that in 1997, about

900 million bushels of soybeans was exported and the domestic production of soybean meal and soybean oil was 33.7 million metric tons (mmt), and 8 million metric tons respectively. Sources from USDA reports[6] on world soybean trade also provide information that the U.S. produced about 47% of the world's soybean production while Brazil and Argentina produced only 21% and 13% respectively over the period 1998-2001.

On a slightly different note, researchers have argued that the increase in the domestic uses of soybean has fueled the amount of soybeans that is produced and exported. According to the United States Department of Agriculture statistics, global production of both soybeans and soybean meal has been increasing steadily since 1996. In 1996, the soybean production occupied about 50.5 per cent, or 132.22 million metric tons, of the world's total oilseed output, which stood at 261.40 million metric tons. In January 2001, the estimated figure for world's production of soybean reached 167.18 million metric tons, which was approximately 50.1 per cent of the global oilseed output at 303.47 million metric tons.

As an example in its domestic use, one of the reasons behind the upward trend in soybean production and export comes from the demand for soybean meal in animal feed. As global demand for meat consumption rises, the demand for animal feed also increases. In fact, the Food and Agriculture Organization (FAO) statistics shows that global meat production increased by 13.16 per cent from 206.24 million metric tons in 1996 to 237.5 million metric tons in 2001. Subsequently, the global soybean meal trade is likely to continue to increase steadily, with nearly 15 per cent growth rate since 1996/97, in which a total of 34.30 million metric tons was traded.

[6]Source: USDA, WASDE-366-23, September 12, 2000

In 2000/01, the USDA predicted that the global soybean meal trade volume will rise to slightly over 40 million metric tons given the two factors that encourage soybean meal trade; low prices and the use of soybean meal as a substitute for protein source in animal feed. On October 9, 2002, the American Soybean Association (ASA) announced a record year for U.S. soybean exports. In formation gathered from the U.S. Department of Agriculture, showed that as at the end of the 2001/02 Marketing Year, the U.S. soybean exports had reached 29.9 million metric tons (mmt), the equivalent of more than 1.1 billion bushels (bu) which was up by 86.6 million bushels from the previous year, an increase of 8.5 percent. The report also indicated that about 40 percent of the total 2001 U.S. soybean crop was exported as whole soybeans. Thus Soybeans greatly contribute to the U.S. balance of trade because soybean and soy product exports are the highest value U.S. agricultural commodity export with an annual value of nearly $7 billion.

In spite of the controversy surrounding biotech-enhanced products (including RR soybeans) in some European countries, U.S. soybean exports to the European Union (EU), the largest combined market for U.S. soybean exports, exceeded 7.7 million metric tons (285 million bushels) in 2002. That's 34 million bushels more than it was the previous year, an increase of 13.5 percent more U.S. soybeans exported to the EU.

Even though U.S. soybean exports increased in nearly all major market areas, during Marketing Year 2001/02, U.S. soybean exports to China fell by about 20% or 42 million bushels. This was due to a new import regulation that was imposed by the Chinese government. Fortunately however, exports to the Western Hemisphere more than made up for the loss in China. Exports to countries such as Mexico, Canada, Colombia, Costa Rica, Barbados, Ecuador, Venezuela, Trinidad, and for the first time in 40 years sales to Cuba, totaled more than 217 million bushels, up 55.7 million bushels, an increase of about 34.4 percent. Furthermore, exports to Japan and Korea were increased by 6 percent, and by 7 percent to Taiwan.

Subsequently given the surge in soybean production for the domestic and the export markets, it is therefore important to note that the role of international trade in the soybean industry and hence this model cannot be overemphasized. Especially since this upward trend in soybean export is likely to continue, as demand for soybean meal grows in animal feed, particularly in the European Commission, because of the ban on the use of Meat and Bone Meal (MBM) in compound feed.

9.5 Model with International Trade

9.5.1 *Assumptions*

While most of the major assumptions made earlier in the basic model still hold, a few considerations are made here to allow for trade. In the basic model, I 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, the model with multiple markets for soybeans is considered in this study. It is therefore important to emphasize that, in this section, I extend the basic model discussed earlier to incorporate the possibility of trade between the U.S and the 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.

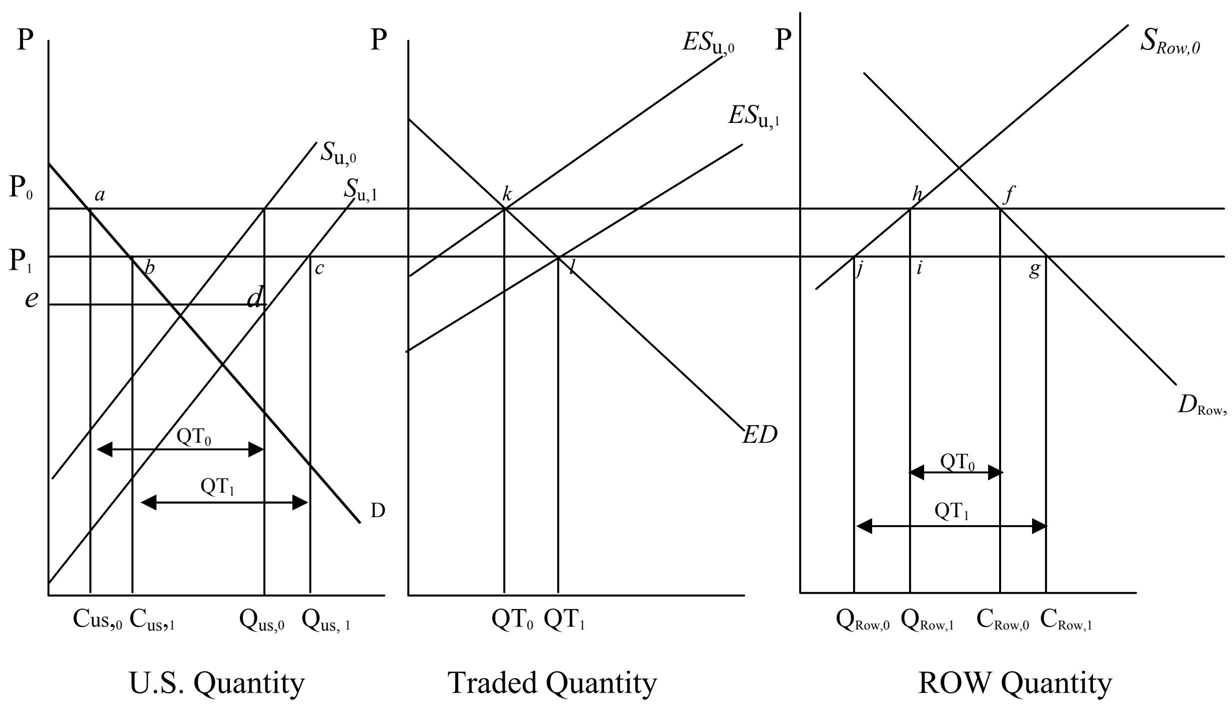
Finally, I assume that the law of one price holds in this model. Therefore a single equilibrium world price is assumed in the model hence all regions in the U.S. are faced with the same price and that regional prices differ only by transportation costs.

9.5.2 The Empirical Model

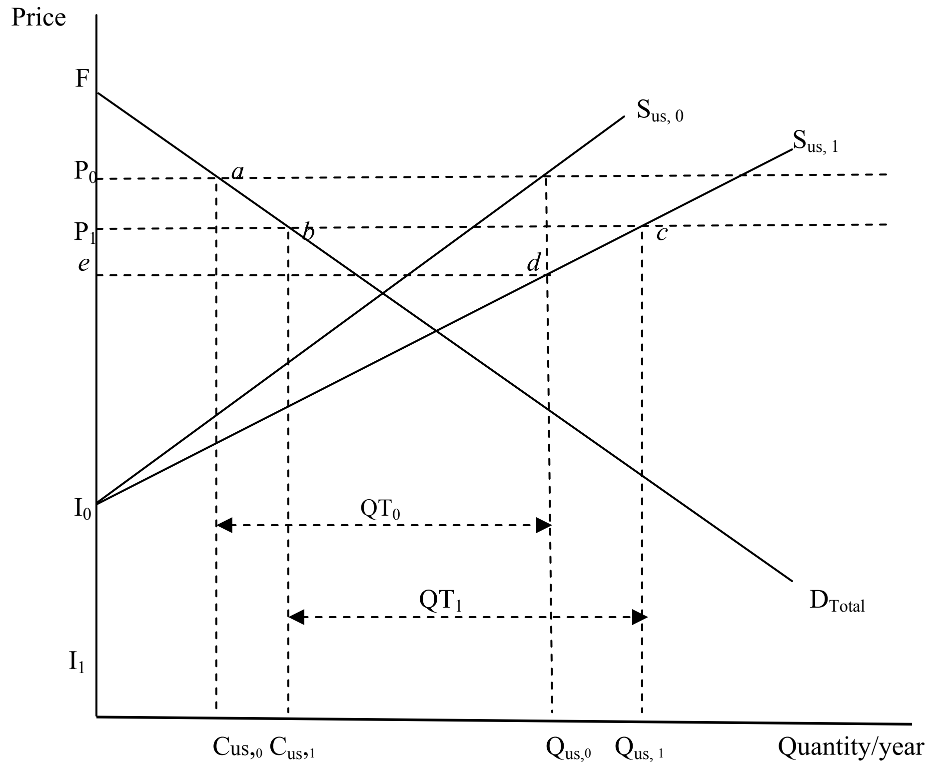
I model the world soybean market for trade between the U.S. a large open economy, and the ROW where the market clearing condition is ensured by equating excess supply (i.e. the difference between the domestic demand and supply) and excess demand (i.e. the difference between the ROW demand and supply). The Marshallian surplus distribution that results from the adoption and trade of soybean produced in U.S. which results in a parallel supply shift is presented graphically in figure 9 below.

Figure 9. 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 9 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.

I 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 9 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 9 above, I 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) I 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.

9.5.3 *Estimated Equations when Trade is Incorporated Into the Model*

To estimate the economic surpluses discussed in this study, I follow the model proposed in Alston, Norton and Pardey 1995, p. 216. In this case, unlike the basic model, I 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:

$$Q_{us} = \alpha_{us} + \beta_{us}(P + k)$$
$$= (\alpha_{us} + \beta_{us}k) + \beta_{us}P, \qquad (21)$$

U.S. domestic demand:

$$C_{us} = \gamma_{us} - \delta_{us} P, \qquad (22)$$

ROW supply:

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

and

ROW demand:

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

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:

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

and

$$Z = -(P_1 - P_0) / P_0$$

$$= \varepsilon_{us}K / [\varepsilon_{us}+S_{us}\eta_{us}+(1- S_{us})\eta^{ED}], \tag{26}$$

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, I applied the following to compute the consumer and producer gains and losses:

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

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

$$\Delta PS_{ROW} = -P_0 Q_{ROW,0}\, Z(1 + 0.5\, Z\, \varepsilon_{ROW}), \tag{29}$$

$$\Delta CS_{ROW} = P_0 C_{ROW,0}\, Z\, (1 + 0.5\, Z\, \eta_{ROW}), \tag{30}$$

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

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:

$$\Delta TS_{us} = 0.5 P_0 Q_{us,0}\, K_{us}\, (1 + Z\, \eta_{us}), \tag{32}$$

$$\Delta CS_{us} = P_0 C_{us,0}\, Z\, (1 + 0.5\, Z\, \eta_{us}), \tag{33}$$

and

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

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

In a recent paper, Alston, Marra, Pardey, and Wyatt (1998) 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 10. Cost-Reduction and Output Gain Due to a Technology-Induced Supply Shift due to RR Soybean Adoption

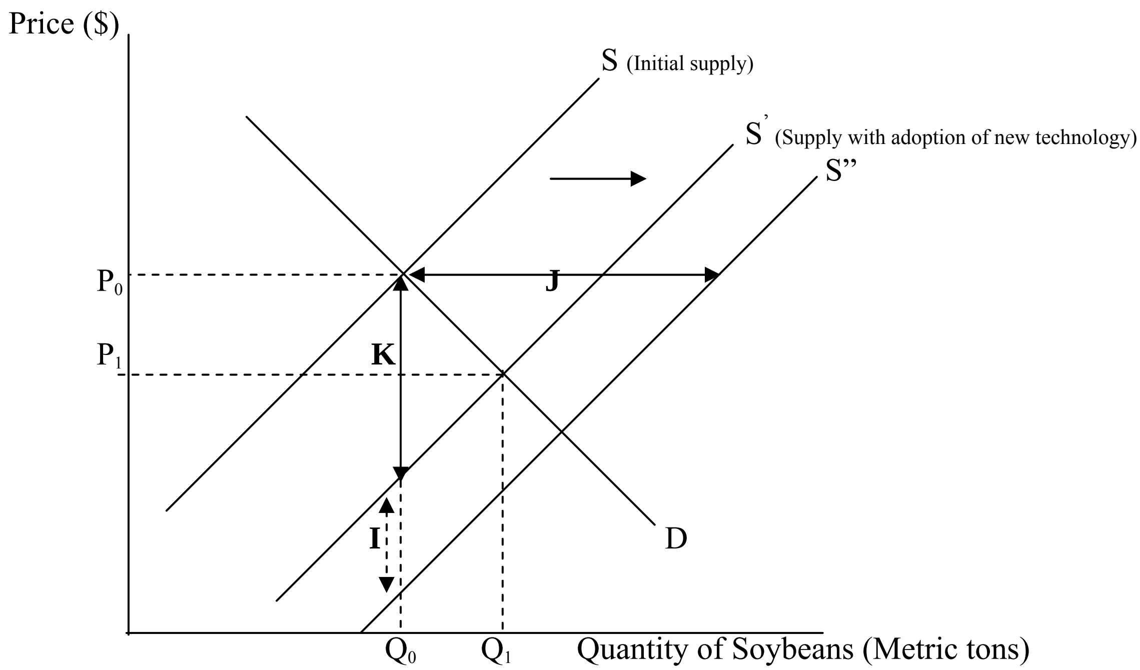


Figure 10, briefly summarizes the parameters that must be estimated and generally suggests the data that are needed in order to assess the market impact of the adoption of the new technology (RR soybeans). While the ***K*** parameter represents the net gain in terms of a decrease in production costs, 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'.

9.7 *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). Using the information above, I estimated the *K, J* and *I* parameters as discussed in the succeeding sections.

9.7.1 *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. Using the yield increases (ΔY) in kg/ha due to the adoption of the RR soybean technology, the adoption rate (t) expressed as the proportion of the total area under the new technology (RR Soybeans), and the total soybean acreage (A) in ha. By definition:

$$J = \Delta Y * t * A. \tag{33}$$

To allow for the calculation of the change in supply or the coefficient by which the supply curve moves with the new technology, I 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:

$$j = J/Q. \tag{34}$$

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, $j = (\Delta Y * t)/Y$.

9.7.2 *The I Parameter (Adoption Costs)*

I define the parameter *I* as the increase in per-unit input costs necessary to gain the (J) production increase. Here I 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:

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

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:

$$c = I/P = (\Delta C * t) / (Y*P). \tag{36}$$

9.7.3 *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:

$$k= \{J * \nabla \}- I . \tag{37}$$

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,

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

Therefore using equation (37) above,

$$k= [J * (1/\varepsilon) * (P / Q)] - I, \qquad (39)$$

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:

$$k/P = \{(P * j) / \varepsilon\}/P - (I / P) \qquad (40)$$

and,

$$K= (j / \varepsilon) - c. \qquad (41)$$

The data sources for this computation 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.

9.8 Compiling Data for Economic Surplus Computation

In the previous section I 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.

9.8.1 *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 (1994) 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).

9.8.2 *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.

9.8.3 *Cost of Adoption*

The data on the cost of adoption used for this study was taken from the information provided by survey respondents. In estimating the cost, I summed up the respondents' per acre cost of inputs needed to adopt the new technology (i.e. expenses on seeds, herbicide product, herbicide application and harvesting and equipment cost).

Chapter 10

10.1 Market Impact 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. I do not include the analysis of economic surplus gains by farmers in different regions nor do I 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 16 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 16. 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 16. Continuation	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 16 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).

Chapter 11

11.1 Summary and Conclusion

The goal of this study has been to identify the factors that influence the adoption of no-till technology and Roundup Ready soybean technology individually and the relevant factors that explain the concurrent adoption of no-till and Roundup Ready soybean technologies. The study was also extended to ascertain the market impact of the adoption of the new agricultural technologies, particularly noting the changes in surpluses gained or lost by producers and consumers in the United States and the rest of the world.

The intent here is to attempt to understand in part how and why U.S. soybean farmers surveyed in 2002 allocated their soybean acreages between traditional and GM soybean varieties *vis-à-vis* the use of either no-till or a tillage farming practice when faced with the opportunity of choosing one or neither technologies. Most importantly, this study seeks to address the question-whether farmers adopting no-till are also adopting the use of Roundup Ready soybean technology. To achieve this objective the FGLS and Tobit models were used for the single adoption; however a simultaneous equation model was used to help explain the concurrent adoption of the two technologies. In order to test for complementarity, I appeal to the theory of supermodularity to investigate the possible presence of complementarity. Finally, regarding the market impact analysis I used the Alston and Pardey economic surplus approach.

The current study finds evidence that the introduction of RR soybeans has had a significant impact on the adoption of no-till technology. The survey reveals that farmers place significant value on the better weed control system and other non-pecuniary benefits such as human and environmental benefits. However, there is a significant negative impact of market uncertainty on the adoption of RR soybean technology. This is not surprising given the unsettled ethical issues on the safety of the human consumption of GM crops. Should the international consumer resistance against GM crops continue to increase, the impact of the value of market uncertainty will be stronger since it could even cause the price of RR soybeans to decrease well below that of conventional soybeans. The level of education and farm size were found to play a positive key role in explaining the adoption of both no-till and RR soybeans as well as the experience of the farmer. Our results show that the higher the level of education of the farmer and the more experienced he was in farming, the higher the probability of adoption. The percentage of land owned however did not explain very much of the adoption process although it had a positive impact on the adoption of both no-till and RR soybeans.

Of the many factors examined, the result was most surprising with the impact of the cost difference and the yield difference between RR soybean and conventional varieties on the probability of adoption. Though they had the expected signs, with the former having a negative impact on adoption and the later, a positive impact, their levels of significance were not very high with respect to the individual adoption of the technologies. However, these factors were very significant in fact at the 5% level in the simultaneous adoption model. This seems to suggest that although farmers may least consider yield and cost differences when they adopt the technologies separately, they do factor them considerably in their farming decision when they have to combine the two technologies together. A possible reason in the difference in attitudes may stem from the fact that using the two together reduces the opportunity to diversify their resources into other conventional or traditional technologies (portfolios). In that case the benefit of transitioning from the old to the new technology becomes very dependent on, and is constrained by the maximum yield they will realize and the level of cost minimization they can achieve. Since a significant percentage of the total cost of adoption discussed in this paper can be attributed to the cost of herbicide and pest control, one can certainly argue that the significant impact of the cost difference supports the fact that the relative effectiveness of agro-biotechnologies against that of conventional herbicide and pest control practices is one of the key drivers of adoption. This also confirms arguments made in previous studies for example, Marra et al. (2001) who found that the depreciation and diminished effectiveness of conventional pest control practices is the most significant factor contributing to the rapid adoption and diffusion of bollgard (BG) technologies.

Regarding the extent of adoption of the two technologies, we find that farm size, proportion of land used for Roundup Ready, convenience factors, years of farming and the level of education had a significant effect on the farmer's participation in the conservation program (no-till). In fact we find that the factors identified, significantly increased the likelihood of participation in the use of no-till technology. With respect to the extent of adoption of Roundup Ready soybeans, farm size, acreage in no-till, cost difference between Roundup Ready soybean and traditional varieties, yield difference, and the level of education significantly influenced the level of participation or adoption of the technology. For example, our results suggests that a marginal increase in yield difference could lead to an increase in Roundup Ready acreage by 47 percent for those who are currently using less than 100 percent of their land for the technology. However, overall, it was realized that the probability of farmers using 100 percent of land (ξ_2) for a given technology was lower.

Using a system of simultaneous equations and comparing the results to that of two separate single probit estimated equations, I find that there we cannot neglect the simultaneity existing between the decision to adopt no-till and RR soybeans. In fact the results support the fact that the decision to adopt no-till is influenced by the decision to adopt RR soybeans and *vice versa*. Thus, the use of herbicide tolerant crops encourages more farmers to adopt no-till.

It is also concluded that the two technologies are likely to be complementary to each other. We draw this inference based on the F test conducted on the dummy variables that was created for the four possible technological combinations which rejects the null hypothesis of no complementarity between the two technologies. This is also validated by the confidence interval constructed for the linear combination of the estimated parameters of the exclusive dummies in our performance function. It is realized that the value of the estimated confidence interval at the 95% level, lies in a positive range of (0.03-0.16), hence we can conclusively argue that $\hat{C}$ is positive, supporting complementarity. Although the approach used does not provide sufficient evidence to fully justify the stated conclusion, our failure to accept the null hypothesis establishing the absence of complementarity, leaves no doubt that there is a positive correlation between the two technologies. Thus, we establish the necessary condition for the presence of complementarity between the two technologies.

The goal of the market impact analysis was 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 is considered and the relevant formulae needed to calculate the surplus measures are developed and discussed. 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. Undoubtedly, consumers in the ROW gain from the worldwide lower commodity prices due to the adoption by the United States. Apparently, since RR soybeans are basically produced in the United States by Monsanto Corporation, a considerable share of the welfare gains of the innovation goes to the producers in the U.S. at the expense of countries in the rest of the world that do not adopt the improved soybean varieties. This however reveals one weakness or limitation in the current study but opens an opportunity for future extensions. In the sense that since this paper does not include the monopoly power of Monsanto over the production and sale of RR soybeans it is not clearly shown in this study exactly how much farmers benefit from such an adoption. It is possible that a greater portion of the U.S. producer surplus goes to Monsanto Corporation in the form of monopoly profits. A future extension of this model recognizing Monsanto's monopoly profits as a component of producer surplus will be very interesting. 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.

It is worth noting that there are many factors that influence the size and distribution of the economic benefits stemming from the adoption of RR soybeans. Although this study has attempted to capture a good number of these factors, there are yet others, for example, the non-market benefits (non-pecuniary benefits) such as convenience factors of simplicity and flexibility in weed control systems, insurance value of crop protection associated with insect –resistant GM crops, the value of human and environmental safety etc. which have not been quantified and included in the market impact analysis. The impact of these non-market benefits may be significant as demonstrated in our adoption model and also reported in Marra et al. (2004) and hence might affect the size and distribution of the surpluses in the current analysis. It will be prudent in the future to find a way to include these non-pecuniary factors in our 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. The emergence of several competing varieties of biotech crops and the evolving pest management practices required for the biotech crops may also affect pesticide use and ultimately the adoption of such technologies which will invariably change the size and distribution of benefits. Lastly, because of the lack of adequate cost data on no-till technology, our market impact analysis of the simultaneous adoption was not fully achieved, this will likely change the size and distribution of surpluses if considered in the future. Given the ethical issues surrounding the use of GMOs, it will also be interesting to ascertain how our estimated surpluses will change for a situation where consumers in the U.S. boycott or show resistance to the GMO product.

In conclusion this study adds to the existing literature in a number of important ways. First and foremost, it accounts for the impact of non-pecuniary factors on the adoption of new technologies and combining them with pecuniary factors to explain the adoption process. Importantly, it also provides evidence on the need to consider the endogenous nature of the two adoption decisions and identify the factors that drive such a simultaneous adoption process. Finally we extend our model to verify the impact of the adoption process on economic agents, i.e., Producers and consumers (domestic and foreign). Our results suggest that while producers and consumers in the adopting country gain some welfare benefits, the economic surplus accrued by consumers is offset by producer losses.

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Appendix A. Conservation Tillage Trends, 1990-2002

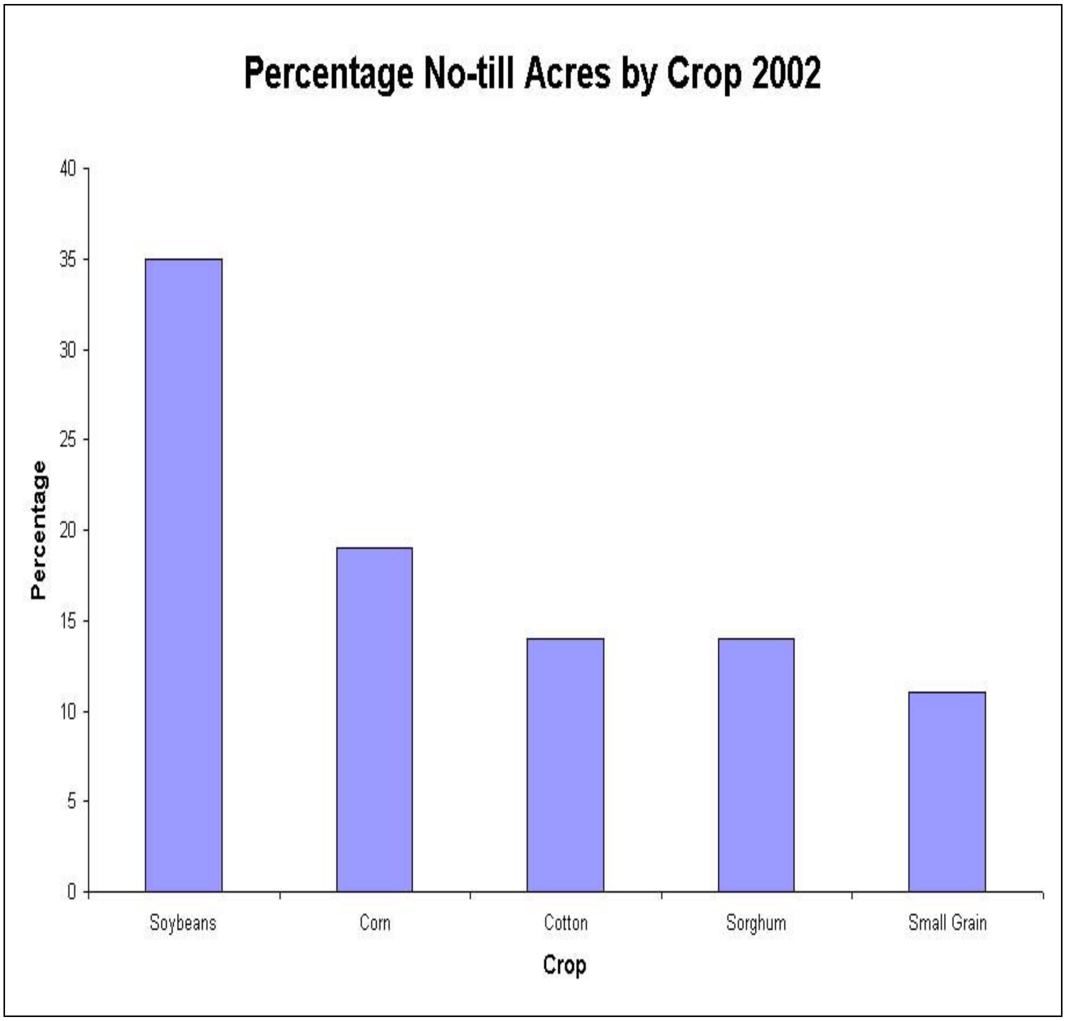
(Millions of Planted Cropland Acres)

Tillage System	**1990**	**1992**	**1994**	**1996**	**1998**	**2000**	**2002**
No-Till/Strip-Till*	16.9 (6.0%)	28.1 (9.9%)	38.9 (13.7%)	42.9 (14.8%)	47.8 (16.3%)	52.2 (17.6%)	55.3 (19.6%)
Ridge-till*	3.0 (1.1%)	3.4 (1.2%)	3.6 (1.3%)	3.4 (1.2%)	3.5 (1.2%)	3.3 (1.1%)	2.8 (1.0%)
Mulch-till*	53.3 (19.0%)	57.3 (20.2%)	56.8 (20.0%)	57.5 (19.8%)	57.9 (19.7%)	53.5 (18.0%)	45.0 (16.0%)
Conservation Tillage Subtotal	73.2 (26.1%)	88.7 (31.4%)	99.3 (35.0%)	103.8 (35.8%)	109.2 (37.2%)	109.1 (36.7%)	103.1 (36.6%)
Reduced-till (15-30% cover)	71.0 (25.3%)	73.4 (25.9%)	73.2 (25.8%)	74.8 (25.8%)	78.1 (26.2)	61.3 (20.6%)	64.1 (22.8%)
Intensive-till (<15% cover)	136.7 (48.7%)	120.8 (42.7%)	111.4 (39.3%)	111.6 (38.5%)	106.1 (36.2)	127.1 (42.7%)	114.3 (40.6%)
All Planted Acres	281.0	282.9	283.9	290.2	293.4	297.5	281.4

*No-till, Strip-till, Ridge-till, and Mulch-till are all considered forms of Conservation Tillage

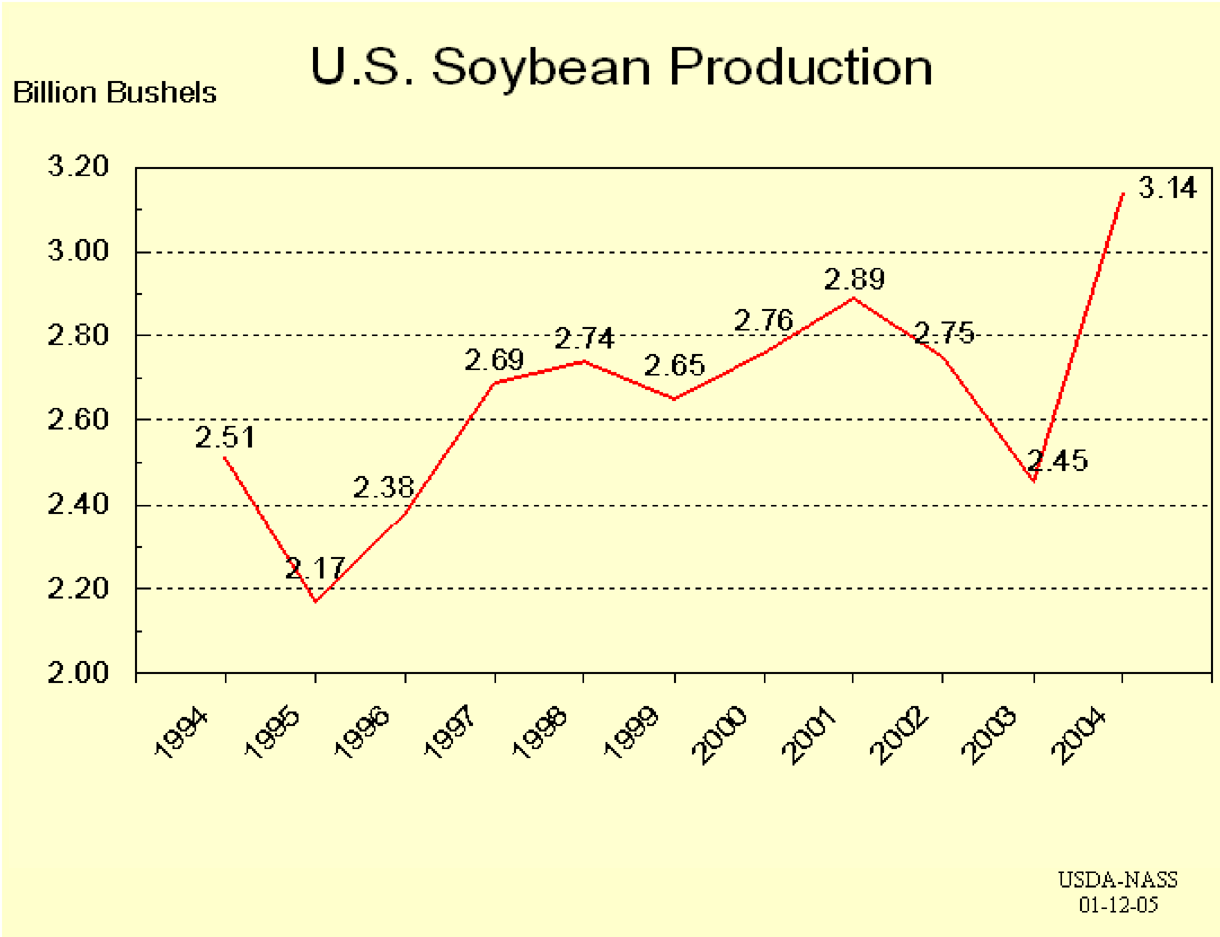
Source: CTIC, 2002 survey report

Appendix B. Percentage of U.S. No-till Acres by Crop, 2002.



Source: Conservation Tillage technology Information Center (CTIC), 2002 survey report

Appendix C. A Graph Showing U.S. Soybean Production 1994-2004



Appendix D. Complementarity Test Results

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
NRR_NNT	1.10543	0.01463	75.54	<.0001
RRonly	0.06895	0.04343	1.59	0.1131
NTonly	0.9921	0.01858	53.4	<.0001
NT_RR	0.04373	0.05776	0.76	0.4494
farmsize	-0.04306	0.09149	-0.47	0.6381
farmsizesq	3.81E-06	2.21E-05	0.17	0.8635
tcostdif	-7.2E-05	0.00025	-0.29	0.7733
vtime_rr	0.000138	0.000506	0.27	0.786
vhumenv	-0.1635	0.11689	-1.4	0.1626
vuncseed	-6.7E-05	0.000393	-0.17	0.8639
vtime_rt	-0.047	0.08073	-0.58	0.5608
vconv_rt	5.45E-05	0.000277	0.2	0.8441
farmyears	-0.06804	0.0626	-1.09	0.2777
time_pf	1.97E-05	0.000136	0.14	0.8851
educ	0.6884	0.61227	1.12	0.2615
educ2	-0.01585	0.03275	-0.48	0.6286
region	-1.54506	2.39128	-0.65	0.5186

F Test : Results for Complementarity

Source	DF	Mean Square	F Value	Pr > F
Numerator	1	705.03711	3.72	0.0544
Denominator	419	189.45670		