Off-Farm Work and the Adoption of Agricultural Innovations

Technological change has been acknowledged as a critical component of productivity and economic growth (Solow, 1994; Griliches, 1995). The rapid adoption and diffusion of new technologies in U.S. agriculture has sustained growth in agricultural productivity and ensured an abundance of food and fiber (Huffman and Evenson, 1993). Technological innovations and their adoption have also changed the way farm households regard employment choices (Binswanger, 1974, 1978). Labor-saving technologies, in particular, have allowed farm household members to increase income by seeking off-farm employment (Mishra et al., 2002).[21]

[21]Off-farm employment was also facilitated by economic growth in the nonfarm economy, improved infrastructure (communications and transportation), as well as education level of farm household members (Banker and MacDonald, 2005).

While profitability (i.e., the extent of yield increases and/or reduction in input costs from an innovation relative to the costs of adoption and current management practices) plays a key role in technology adoption, most studies acknowledge that heterogeneity among farms and farm operators often explains why not all farmers adopt an innovation in the short or long run (Batte and Johnson, 1993; Feder and Umali, 1993; Khanna and Zilberman, 1997; Lowenberg-DeBoer and Swinton, 1997; Rogers, 1961, 1995) (see box, "Factors Influencing Technology Adoption").

Still, assessments of technology adoption using the traditional economic tools pioneered by Griliches (1957) have proven insufficient to explain differing adoption rates for many recent agricultural innovations. The standard measures of farm (accounting) profits, such as net returns (to management), give an incomplete picture of economic returns because they usually exclude the value of management time (Smith, 2002). For example, herbicide-tolerant soybeans were rapidly adopted despite showing no significant advantage in net returns over conventional soybeans. On the other hand, adoption of technologies such as integrated pest management (IPM) has been rather slow despite explicit economic and environmental advantages (Fernandez-Cornejo and McBride, 2002; Smith, 2002). This led to the hypothesis that adoption is driven by "unquantified" advantages, such as simplicity and flexibility, which translate into reduced managerial intensity, freeing time for other uses. An obvious use of managers' time is off-farm employment.

Off-Farm Work as a Factor in Early Studies of Technology Adoption

Early studies of technology adoption viewed off-farm income as influencing adoption of "conservation" practices by providing "supplemental income" to finance conservation expenditures (Blase, 1960). Ervin and Ervin (1982), on the other hand, argued that "off-farm income could reflect the need for supplemental income for family living expenses and essential farm production expenses other than conservation and less time to implement and maintain unfamiliar practices." Survey results on farmers' motivation to seek off-farm income and their view of such employment as permanent rather than temporary, suggest that motivation is closer the view of Ervin and Ervin.

Factors Influencing Technology Adoption

Rural sociologists recognized early that essential differences among farmers can explain why they do not adopt an innovation at the same time. In addition, the characteristics (perceived or real) of an innovation are widely known to influence the adoption decision (Rogers, 1995; Batz et al., 1999). Economists and sociologists have made extensive contributions to the literature on the adoption and diffusion of technological innovations in agriculture (e.g., Griliches, 1957, Feder et al., 1985; Rogers, 1962, 1995). Such research typically focuses on the long-term extent of adoption and the factors that influence the adoption decision.

Farm Structure/Size

A basic hypothesis regarding technology transfer is that the adoption of an innovation will tend to take place earlier on larger farms than on smaller farms. Just et al. (1980) show that, given the uncertainty and the fixed transaction and information costs associated with innovations, there may be a critical lower limit on farm size that prevents smaller farms from adopting. As these costs increase, the critical size also increases. It follows that innovations with large fixed transaction and/or information costs are less likely to be adopted by smaller farms. However, Feder et al. (1985) point out that lumpiness of technology can be offset by the emergence of a service sector (i.e., custom service or consultant). Disentangling farm size from other factors hypothesized to influence technology adoption has been problematic. Feder et al. (1985) caution that farm size may be a surrogate for other factors, such as wealth, risk preferences, and access to credit, scarce inputs, or information. Moreover, access to credit is related to farm size and land tenure because both factors determine the potential collateral available to obtain credit.

Human Capital

The ability to adapt new technologies for use on the farm clearly influences the adoption decision. Most adoption studies attempt to measure this trait through operator age, formal education, or years of farming experience (Fernandez-Cornejo et al., 1994). More years of education and/or experience is often hypothesized to increase the probability of adoption whereas increasing age reduces the probability. Factors inherent in the aging process or the lowered likelihood of payoff from a shortened planning horizon over which expected benefits can accrue would be deterrents to adoption (Barry et al., 1995; Batte and Johnson, 1993). Younger farmers tend to have more education and are often hypothesized to be more willing to innovate.

Risk and Risk Preferences

In agriculture, the notion that technological innovations are perceived to be more risky than traditional practices has received considerable support in the literature. Many researchers argue that the perception of increased risk inhibits adoption (Feder et al., 1985). Hiebert (1974) and Feder and O'Mara (1981) show that uncertainty declines with learning and experience. Innovators and other early adopters are believed to be more inclined to take risks than are the majority of farmers.

Tenure

While several empirical studies support the hypothesis that land ownership encourages adoption, the results are not unanimous and the subject has been widely debated (e.g., Feder et al., 1985). For example, Bultena and Hoiberg (1983) found no support for the hypothesis that land tenure has a significant influence on adoption of conservation tillage. The apparent inconsistencies in the empirical results are due to the nature of the innovation. Land ownership is likely to influence adoption if the innovation requires investments tied to the land. Presumably, tenants are less likely to adopt these types of innovations because the benefits of adoption will not necessarily accrue to them.

Credit Constraint, Location, and Other Factors

Any fixed investment requires the use of own or borrowed capital. Hence, the adoption of a non-divisible technology, which requires a large initial investment, may be hampered by lack of borrowing capacity (El-Osta and Morehart, 1999). Location factors—such as soil fertility, pest infestations, climate, and availability or access to information—can influence the profitability of different technologies across different farms. Heterogeneity of the resource base has been shown to influence technology adoption and profitability (Green et al., 1996; Thrikawala et al., 1999). Irrigation may also influence adoption. Irrigation generally increases yields and profitability and reduces production risk. However, irrigation may also increase risk; for example, it may encourage certain pest populations (Harper and Zilberman, 1989). Contractual arrangements for the production/marketing of the crop are also believed to influence the adoption of certain technologies. Contracts often specify the acreage to be grown or quantity and quality of product to be delivered and may also require the application of certain inputs and practices.

McNamara et al. (1991) used empirical evidence from peanut producers to conclude that integrated pest management (IPM) required substantial time for management and that off-farm employment may present a constraint to IPM participation. Fernandez-Cornejo et al. (1994), Fernandez-Cornejo (1996, 1998), and Fernandez-Cornejo and Jans (1996) found similar results for vegetable and fruit producers. Wozniack (1993) considered livestock feeding innovations and showed that off-farm wage income was inversely related to the likelihood of early adoption and acquiring information.[22] More recent survey results show that operators of high-sales, large, and very large farms—which depend on farm revenues more (and therefore less on off-farm employment) than smaller farms—tend to adopt more management-intensive technologies. For example, around 18 percent of the operators of larger farms adopted precision farming in 1998. In contrast, only 3 percent of the operators of smaller farms (who worked more off-farm hours) adopted precision farming (Hoppe, 2001).

[22]Measures used included off-farm income as a percentage of total household income (Ervin and Ervin, 1982) or days (or hours) per year that the operator worked off-farm (Fernandez-Cornejo, 1996, 1998; Fernandez-Cornejo and Jans, 1996).

Weaknesses of Early Studies

While insightful, early studies failed to model the interaction of technology adoption and off-farm employment decisions based on the underlying economic theory and consistent with farmers' optimization behavior. Rather, they simply included some measure of off-farm work as one explanatory variable in the adoption decision. Early studies also had some econometric problems, such as not accounting for simultaneity of the off-farm work and adoption decisions and the possibility of self-selection (see appendix 2).[23] Finally, earlier studies did not examine the relationship between technology adoption and household income from farm and off-farm sources.

[23]Self-selection occurs because farmers are not assigned randomly into groups (e.g., farmers that work off farm or not, adopt or not) but make the choices themselves. Therefore, group members may be systematically different, and these differences may manifest themselves in farm performance and could be confounded with differences due purely to working off farm (or adoption). This situation, called self-selection, may bias the statistical results unless it is corrected (appendix 2).

Modeling the Interaction Between Off-Farm Work and Adoption Decisions

To address these issues, we examine the interaction of off-farm income-earning activities and adoption of four agricultural technologies (see box, p. 22) of varying managerial intensity, including herbicide-tolerant crops (Fernandez-Cornejo and Hendricks, 2003; Fernandez-Cornejo et al., 2005), precision agriculture (Fernandez-Cornejo and Southern, 2004), conservation tillage (Fernandez-Cornejo and Gregory, 2004), and Bt (*Bacillus thuringiensis*) corn (Fernandez-Cornejo and Gregory, 2004). We also estimated empirically the relationship between the adoption of these innovations and farm household income from onfarm and off-farm sources.

For this purpose, we expanded the agricultural household model to include the technology adoption decision together with the off-farm work participation decisions by the operator and spouse (appendix 2).[24] We developed an econometric model to examine the interaction of off-farm work and adoption of agricultural technologies, as well as the impact of technology adoption on farm household income (from onfarm and off-farm sources) after controlling for such interaction (appendix 2). The model used data from nationwide surveys of corn and soybean farms in 2000-2001.

[24]The agricultural household model (Singh et al., 1986; Huffman, 1980, 1991; Lass et al., 1989; Lass and Gempesaw, 1992; Kimhi, 1994, 2004) combines in a single framework all important economic decisions of the farm household.

We hypothesize that adoption of managerial-saving technologies (such as herbicide-tolerant (HT) soybeans) frees up management time for use elsewhere (notably off-farm employment), leading to higher off-farm income. On the other hand, managerially intensive technologies (such as precision agriculture) would result in less time available for off-farm activities, leading to lower off-farm income.

It is also possible that farmers already working off farm may be more disposed to adopt managerial-saving technologies. This may lead to additional off-farm work and result in even higher off-farm income. Similarly, farmers who are working off farm may be reluctant to adopt managerially intensive technologies.[25]

In either case, we anticipated that adoption of managerial-saving technologies would be associated with higher off-farm income and adoption of managerially intensive technologies would be related to lower off-farm income. (In this report, we show only the empirical validity of the relationship, but not the direction of the causality.)

A two-stage econometric estimation method was used to estimate the empirical model (appendix 2). The first stage, the decision model, examines the factors influencing off-farm work participation and technology adoption decisions. The second stage is used to estimate the relationship between technology adoption and household income.

Technology Adoption and Off-Farm Income

We find that the relationship between the adoption of herbicide-tolerant (HT) soybeans and *off-farm* household income is positive and statistically significant (table 7). The elasticity of off-farm household income with respect to the probability of adoption of HT soybeans (calculated at the mean) is +1.59.[26] That is, after controlling for other factors, a 15.9-percent increase in off-farm household income is associated with a 10-percent increase in the probability of adopting HT soybeans. The adoption of HT soybeans is also positively and significantly associated with total household income (from off-farm and onfarm sources). A 9.7-percent increase in total household income is associated with a 10-percent increase in the probability of adopting of HT soybeans. On the other hand, adoption of herbicide-tolerant soybeans did not have a significant relationship with household income from farming (table 7).

Results for adoption of conservation tillage are similar to those obtained for HT soybeans, but of a lesser magnitude (table 7). Controlling for other factors, the association between the adoption of conservation tillage and off-farm household income is positive and statistically significant (elasticity +0.98). An increase in *off-farm* household income of 9.8 percent is associated with a 10-percent increase in the probability of adopting conservation tillage. The association of adoption of conservation tillage and total household income (including both off-farm and onfarm sources) is positive and statistically significant. The elasticity of total household income with respect to the probability of adopting conservation tillage is +0.46.

[25]As Olfert observes: “Given the nature of nonfarm jobs, where commitments to specific timeframes are frequently more precise than is the case in farming, it is possible that a nonfarm job receives first priority in the allocation of time with farm production undertaken as a second priority.” However, Olfert adds: “It may also be the case that the decision regarding time allocation to farm and nonfarm work is made simultaneously or that the off-farm employment decision influences the type and size of farm that is optimal. Farm enterprises that are less demanding in their commitments may be chosen to permit nonfarm employment. Knowing the time commitments required by the nonfarm job, the farm size and type will be organized to accommodate that schedule. Similarly, given the nature of labour requirements on the farm, a choice will be made about the type and amount of nonfarm work.”

[26]Results are expressed in terms of elasticity—the percent change in a particular variable (e.g., household income) relative to a small percent change in adoption of the technology from current levels, controlling for other factors. The elasticity results can be viewed in terms of the aggregate change in a particular variable (across an entire agricultural region or sector) relative to aggregate increases in adoption (as more and more producers adopt the technology). However, in terms of a typical farm —that has either adopted or not— the elasticity is usually interpreted as the (marginal) farm-level change associated with an increase in the probability of adoption, away from a given, or current, level of adoption. As shown in appendix 2, the regression model controls for farm location and typology, operator age, education, and experience, number of children, price of the crop, a measure of specialization on soybean/corn production, a measure of the extent of livestock operations, farm size, and proxies for local labor market conditions.

Table 7

Elasticities of farm household income with respect to the probability of adopting technologies of differing managerial intensity

Elasticity of	With respect to adoption of: Yield monitors	Bt corn[1]	Conservation tillage	Herbicide-tolerant (HT) soybeans
Onfarm household annual income	0[2]	0[2]	0[2]	0[2]
Off-farm household annual income	-0.84	0[2]	+0.98	+1.59
Total household annual income	0[2]	0[2]	+0.46	+0.97

[1]Bt = Bacillus thuringiensis)
[2]Statistically insignificant underlying coefficient. The underlying coefficients and their standard errors are shown in appendix 2.

On the other hand, the relationship between the adoption of yield monitors (an important component of precision agriculture) and off-farm household income is negative and statistically significant (elasticity = -0.84) when we control for other factors. That is, a decrease in off-farm household income by 8.4 percent is associated with a 10-percent increase in the probability of adopting yield monitors. Adoption of yield monitors did not have a statistically significant association with either farm household income or total household income. These results are quite different from those for HT soybeans and conservation tillage. This empirical evidence suggests that yield monitoring techniques are management-intensive compared with the other two technologies, which spare management time.

Finally, the relationship between the adoption of Bt corn with either off-farm or onfarm household income was not statistically significant, indicating that Bt corn may be managerially neutral.

These results are consistent with anecdotal evidence (see box “Selected Agricultural …”) that herbicide-tolerant soybeans save managerial time because of the simplicity and flexibility of weed control. Conservation tillage is also believed to save managerial labor, but to a lesser degree than HT soybeans. Our results for yield monitoring are also consistent with anecdotal evidence that precision farming techniques in general are managerially using. Before the commercial introduction of Bt corn in 1996, most farmers accepted yield losses rather than incur the expense and uncertainty of chemical control. For those farmers, the use of Bt corn was reported to result in yield gains rather than pesticide savings, and savings in managerial time were small.

Selected Agricultural Technologies and Their Managerial Intensity

Herbicide-tolerant (HT) soybeans contain traits that allow them to survive certain herbicides that previously would have destroyed the crop along with the targeted weeds. This allows farmers to use more effective postemergent herbicides, expanding weed management options (Gianessi and Carpenter, 1999). The most common herbicide-tolerant crops are resistant to glyphosate, a herbicide effective on many species of grasses, broadleaf weeds, and sedges. Adoption of HT soybeans has risen rapidly since commercial availability in 1996. HT soybean use rose quickly to about 17 percent of U.S. soybean acreage in 1997 and reached 87 percent in 2005 (Fernandez-Cornejo and McBride, 2002; USDA, NASS, 2003).

Herbicide-tolerant soybeans save managerial time because of the relative simplicity and flexibility of the weed control program. The herbicide-tolerant technology allows growers to apply one herbicide product over the soybean crop at any stage of growth, instead of using several herbicides, to control a wide range of weeds "without sustaining crop injury" (Gianessi and Carpenter, 1999). In addition, using HT soybeans is said to make harvest easier (Duffy, 2001).

Conservation tillage is defined as "any tillage or planting system that maintains at least 30 percent of the soil surface covered by residue after planting" (Conservation Technology Information Center, 2004). It includes no-till, ridge-till, and mulch-till techniques. The impact of conservation tillage in controlling soil erosion and soil degradation is well documented (Edwards, 1995; Sandretto, 1997). By leaving substantial amounts of residue evenly distributed over the soil surface, conservation tillage reduces soil erosion by wind/water, increases water infiltration and moisture retention, and reduces surface sediment and chemical runoff. Adoption of conservation tillage was estimated at 2 percent of planted acreage in 1968 and grew fastest during 1975-85, reaching nearly 28 percent in 1985 (Schertz, 1988). It reached about 37 percent of planted acreage in 2002 (Conservation Technology Information Center, 2004). Conservation tillage is used primarily to grow corn, soybeans, small grains, and cotton.

Conservation tillage is believed to save managerial labor (Sandretto, 1997; USDA, 1998). While it is accepted that adoption of conservation tillage leads to labor savings, its slower rate of adoption compared with HT crops may be because the managerial savings are less.

Bt crops carry the gene from the soil bacterium *Bacillus thuringiensis* (Bt) and are able to produce proteins that are toxic to certain insects. Bt corn, originally developed to control the European corn borer, was planted on 35 percent of corn acreage in 2005, up from 24 percent in 2002. The recent upswing may be due to the commercial introduction in 2003/04 of a new Bt corn variety that is resistant to the corn rootworm.

Before the commercial introduction of Bt corn in 1996, chemical pesticide use was often not profitable to control the European corn borer (ECB) and timely application was difficult (Fernandez-Cornejo and Caswell, 2006). Many farmers accepted yield losses rather than incur the expense and uncertainty of chemical control. For those farmers, the use of Bt corn resulted in yield gains rather than pesticide savings, and managerial time savings were minimal.

Precision agriculture (PA) is often characterized as a suite of technologies used to monitor and manage subfield spatial variability. It includes, for example, global positioning systems, grid soil sampling, yield monitors, and input applicators that can vary rates across a field (Daberkow et al., 2002). These technologies can be used independently or as a package of technologies that includes, for example, the use of grid soil sampling, a variable-rate input applicator, and a yield monitor. PA has been growing relatively slowly. Yield monitors, which provide farmers site-specific data to allow them to vary input application and production practices, are the most extensively adopted PA component. Yield monitors were used in about 33 percent of total corn acreage in 2001 and in about 25 percent of soybean acreage. Adoption of other components of PA is even slower. Adoption of variable-rate applicators reached just 10 percent of corn acreage for fertilizer and 3 percent for pesticides or seeds in 2001 (Daberkow et al., 2002).

Unlike herbicide-tolerant soybeans, which provide savings in management time (and therefore allow operators to obtain higher income from off-farm activities), yield monitors (and precision agriculture in general) are generally believed to be human capital-intensive (Griffin at al., 2004).