Green Subsidies in Agriculture: Estimating the Adoption Costs of Conservation Tillage from Observed Behavior

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Abstract

Due to payoff uncertainties combined with risk aversion and/or real options, farmers may demand a premium in order to adopt conservation tillage practices, over and above the compensation for the expected profit losses (if any). We propose a method of directly estimating the financial incentives required for adopting conservation tillage and distinguishing between the expected payoff and premium of adoption based on observed behavior. We find that the premium may play a significant role in farmers' adoption decisions. In an application to the state of Iowa, we find that if a uniform conservation tillage adoption subsidy program were offered in 1992, over 86% of the subsidy program payments would be an income transfer to existing and low cost adopters.

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The passage of the Conservation Security Act (CSA) in the 2002 US farm bill marks a potentially significant change in the direction of environmental policy with respect to agriculture. Rather than focusing on incentives to retire environmentally sensitive land from production, the CSA targets changes in agricultural practices on working lands. Specifically, the Act authorizes the US Department of Agriculture to make payments to farmers who adopt conservation practices such as conservation tillage. To predict farmer participation and the cost of this program, it is important to *quantitatively* estimate farmers' incentives to adopt such practices.

Adopting conservation practices does not always lead to reduced profit for farmers. In fact, even without any government subsidy, on average over 36% of U.S. acres are in conservation tillage (CTIC 2000). Nevertheless, to the extent that an individual farmer ignores the social benefits of conservation practices, the adoption rate is likely to be lower than socially optimal. Further, even when conservation practices can raise a farmer's expected profit, he may be reluctant to adopt because the practices may be riskier. Specifically, he may require a premium to adopt conservation tillage if he is risk averse, because the net payoff under conservation tillage is often more uncertain (Klemme 1985; Fox et al. 1991). Further, the premium may arise because adoption involves sunk investments (e.g. in human or physical capital) and thus real options may be present (Arrow and Fisher 1974). Then even if he is risk neutral, the farmer may have incentive to wait for more information about the payoffs of both tillage practices before committing the investments. Under either or both cases, the farmer adopts only if the additional profit of conservation practices overcomes the premium.

There is a large literature studying the *incentives* of farmers to adopt conservation practices and new technologies in general (Sunding and Zilberman 2000 provide a review). The incentives are found to depend qualitatively on soil quality, crops grown, and farmer characteristics such as age, education, etc. In spite of this literature, there exists little empirical evidence on the incentive *payments (or subsidies)* that would be needed to induce farmers to adopt conservation practices (and new technologies in general). Thus, there is little empirical evidence on which the likely effectiveness of the CSA can be evaluated or the consequences of setting alternative subsidy levels can be considered.

The reason for this omission is that most of the studies employ discrete choice methods that allow coefficient estimates to be recovered only up to a multiplicative constant. Thus, though probabilities of adoption can be estimated, these estimates cannot be readily converted into dollar compensation levels. Consequently, adoption subsidies have mostly been estimated through stated preference methods (Lohr and Park 1995; Cooper and Keim 1996; Cooper 1997).[1]

This paper contributes to the literature in several ways. First, we adopt a modeling strategy that allows for full recovery of the structural coefficients and hence the ability to directly compute the subsidies needed for adoption. Pautsch et al. (2001) apply a simple version of this model to examine the potential for carbon sequestration in agricultural soils, and Wu et al. (2004) similarly use a discrete choice model to study policies aimed at nonpoint source pollution reduction. Here, we develop a richer version where we incorporate an adoption premium related to uncertainty in addition to changes in expected profit. Second, we decompose the subsidy into two components: the profit loss (or gain) from adoption and the

[1] As an exception, Caswell and Zilberman (1986) estimate the premium for adopting new irrigation technologies by relating the costs of technologies to well depth and electricity rates.

premium associated with uncertainty. In so doing, we confirm the arguments of agronomists and extension agents that conservation tillage pays (Jolly, Edwards, and Erbach 1983; Setia and Osborn 1989; Fox et al. 1991; and Stonehouse 1995): on average in our sample, a farmer gains from adoption. However, the adoption premium may exceed the profit gain, and consequently the farmer may require a subsidy to adopt the practice. The significance and empirical magnitude of these quantities are studied.

Finally, based on the estimated subsidies, we calculate the "supply curve" of conservation tillage and analyze the role of the subsidies in improving environmental performance and as a tool of income transfers to farmers. We find that a significant part of the subsidy (or conservation payments) will be income transfers to existing and low cost adopters. Thus, while a program like the CSA can be expected to yield an increase in the environmentally friendly practice of conservation tillage, a large percent of the funds will be transferred to producers for whom adoption has already occurred. Our results provide some of the first empirical evidence on the potential effectiveness of a program like the CSA in encouraging adoption of conservation tillage.

1. The Adoption Decision

We begin by describing the theoretical justification for the existence of an adoption premium, and why the premium relates directly to payoff uncertainties, thereby allowing separate estimation of the premium and net returns of conservation tillage. Let π_1 be the expected annual net return from using conservation tillage, σ_1^2 be the variance of this return, and π_0 be the return from using conventional tillage. Consider first a simple case where every year the farmer can *freely* change his farming practices between the two choices. If he is risk averse, standard utility theory indicates that he uses conservation tillage if and only if $\pi_1 - R_r(\sigma_1^2, \mathbf{z}_r) \geq \pi_0$ or $\pi_1 - \pi_0 \geq R_r(\sigma_1^2, \mathbf{z}_r)$, where $R_r(\bullet)$ is the risk premium associated with conservation tillage, and $\mathbf{z}_r$ is the set of variables that affect the risk premium, such as farm income and other individual attributes. For simplicity, we assume away the uncertainty in the return of conventional tillage. Typically the return from conservation tillage is more volatile, either because farmers have more experience with conventional till or, more likely, because of the sensitivity of performance under conservation tillage to random weather events (Klemme 1985; and Fox et al 1991). Then π_1 must exceed π_0 by a strictly positive premium for the farmer to adopt conservation tillage.

More realistically, adopting a new tillage practice requires investment in physical and human capital. Moreover, conservation tillage usually leads to lower yields in early years before soil nutrients build up.[2] The lost profit in these years is sunk because it cannot be recovered by reverting back to conventional tillage. Given the uncertainties and the lost profits, a farmer may be reluctant to adopt conservation tillage and will adopt only when he is especially "sure" that adoption will be profitable. Specifically, there is value in delaying the adoption decision until the farmer has acquired enough information about the *payoff* to be sure that the likelihood of unprofitable adoption is sufficiently low. For example, he may wait and observe the performance under various weather conditions of neighbors who have adopted conservation tillage. Since weather typically varies across years, by waiting, the farmer is able to draw more "sample points" about the payoff. That is, new information about the payoff arrives even when the weather shocks are uncorrelated over time. Alternatively, commodity prices are usually serially correlated. Waiting enables the farmer to obtain more updated information about future prices, and thus about the payoff. Therefore, the farmer adopts only when π_1 exceeds π_0 by the option value or premium, $R_p(\sigma_1^2, \mathbf{z}_p)$, where $R_p(\bullet)$ is increasing in σ_1^2, and $\mathbf{z}_p$ is the set of relevant explanatory variables. This reasoning does not depend on the risk attitude of the farmer, and is a standard result in the real options literature (Arrow and Fisher 1974; and Dixit and Pindyck 1994).

Note that both sources of the adoption premium (R_r and R_p) depend on the existence of *uncertainties* in the return of conservation tillage. For example, the existence of sunk costs of adoption alone does not generate a premium. If a farmer knows with certainty the future streams of returns under the two practices, his decision will depend only on the two net present values. In this case, the sunk costs simply enter the streams of returns and affect the NPVs alone, and thus they will not lead to any additional adoption premium.

In summary, due either to risk aversion or to real options, a farmer typically demands a premium for adopting conservation tillage. That is, he adopts if and only if $\pi_1 - \pi_0 \geq P(\sigma_1^2, \mathbf{z})$, where $P(\sigma_1^2, \mathbf{z}) \equiv R_r(\sigma_1^2, \mathbf{z}_r) + R_p(\sigma_1^2, \mathbf{z}_p)$. The premium is zero when the variance is zero. This latter fact is the critical feature that allows estimation of the premium separately from the net returns of conservation tillage.[3]

2. Modeling the Adoption Premium

[2] Lower yields under conservation tillage in the early years may also be due to learning the intricacies of a new management process. We thank an anonymous reviewer for contributing this comment.

[3] It is important to note that, although we do not separate out the two sources of the premium empirically in this paper, they may have distinctive policy implications. For example, if the premium is mainly due to risk aversion, stabilization policies could be used to encourage adoption. If option value is the major factor, providing farmers with more information about conservation tillage could be more effective. It is thus important in future studies to separate the two sources.

We turn now to the modeling strategy for describing farmers' decisions to adopt conservation tillage. In the standard setting, farmers are predicted to adopt conservation tillage if the expected profit from adoption exceeds that from continuing with conventional practices, i.e. when $\pi_1 \geq \pi_0$. The profit functions are assumed known to the farmers, but unobservable to the researcher. An additive error is incorporated to reflect the researcher's omission of relevant variables or misspecification of the profit functions. An expression for the probability of adoption from the researcher's perspective can be then written as

(1) $$\Pr\left[adopt\right] = \Pr\left[\pi_1 \geq \pi_0 + \sigma\varepsilon\right],$$

where ε is typically a standard normal or logistic error and σ is the associated standard deviation multiplier. We write the error term in this somewhat nonstandard way to more easily explain the limitation of this form of the model. The next step is to specify a functional form for the difference in the net returns, typically linear in explanatory variables, e.g., $\pi_1 - \pi_0 = \mathbf{\delta y}$, where the $\mathbf{y}$ is a vector of explanatory variables and $\mathbf{\delta}$ is a vector of coefficients (see, e.g., Soule et al. 2000, Khanna 2001).

There are two limitations of this model for fully understanding adoption decisions. First, there is no explicit formalization of the existence of the premium needed to induce adoption, as the probability of adoption can be written as

(2) $$\begin{aligned}\Pr\left[adopt\right] &= \Pr\left[\pi_1 \geq \pi_0 + \sigma\varepsilon\right] \\ &= \Pr[\mathbf{\delta y} \geq \sigma\varepsilon] \\ &= \Pr[\varepsilon \leq \frac{\mathbf{\delta y}}{\sigma}].\end{aligned}$$

Second, and even more critical for estimating the financial incentives needed to induce adoption, the coefficients on the net returns expression can only be estimated up to the multiplicative constant, σ.

This formulation makes clear the point that is well known among practitioners of discrete choice models: only estimates of the ratios of the coefficients to the standard deviation can be recovered. Consequently, neither the changes in net returns associated with adoption of conservation tillage nor the financial incentives necessary for adoption can be estimated. Analysts must be satisfied with predictions of qualitative changes such as identifying what characteristics of farmers will increase the likelihood of adoption.

Here we propose and implement a conceptual model that both (a) explicitly incorporates an adoption premium to reflect risk aversion and real options, and (b) allows recovery of an estimate of σ, thereby allowing recovery of the individual parameter values. Specifically, we assume that an individual farmer will adopt conservation tillage when $\pi_1 \geq \pi_0 + P,$ where P is the premium. Again, an additive error is used to represent omitted variables or misrepresentation of the net returns statement by the researcher and π_1 is assumed linear in explanatory variables. However, we assume that the expected net returns from conventional tillage are known to the farmer and focus on modeling the returns to conservation tillage as a function of explanatory variables. Thus, we write the probability of adoption as

$$
\begin{aligned}
\Pr\left[adopt\right] &= \Pr\left[\pi_1 \geq \overline{\pi}_0 + P + \sigma\varepsilon\right] \\
&= \Pr[\boldsymbol{\beta}\mathbf{x} \geq \overline{\pi}_0 + P + \sigma\varepsilon] \\
&= \Pr[\varepsilon \leq \frac{\boldsymbol{\beta}\mathbf{x}}{\sigma} - \frac{\overline{\pi}_0}{\sigma} - \frac{P(\sigma_1^2,\mathbf{z})}{\sigma}],
\end{aligned}
\tag{3}
$$

where $P(\sigma_1^2,\mathbf{z})$ represents the premium as a function of its explanatory variables and the bar on $\overline{\pi}_0$ denotes that this variable is known. Note that $\boldsymbol{\beta}\mathbf{x}$ represents the expected net returns to conservation tillage, not the difference in returns between the two practices (represented by $\boldsymbol{\delta}\mathbf{y}$ above).

In this formulation, recovery of the standard deviation multiplier σ is straightforward as it will simply be the inverse of the coefficient estimated on $\bar{\pi}_0$. Thus, by adding information to the model in the form of the expected net profits from conventional tillage, it is possible to estimate the standard error, in turn allowing recovery of the specific parameter values for $\boldsymbol{\beta}$.[4]

Further it seems reasonable to assume that farmers understand well the expected return for conventional tillage as this practice has been used widely over a long period of time. Thus, farmers have substantial experience both in using conventional tillage and in predicting its mean profitability (e.g., in making annual planting decisions). Note that once the data on $\bar{\pi}_0$ are available, the standard deviation multiplier σ and the parameter values $\boldsymbol{\beta}$ are identifiable, independently on whether the risk premium component exists or not.

Turning now to the premium function, note that the theoretical basis for the presence of an adoption premium requires the presence of profit uncertainty of conservation tillage. Although this uncertainty may affect the premium differently under risk aversion and real options, we focus on the magnitude of the premium and how it depends on the uncertainties rather than attempting to identify the source. Since the data set we use is cross-sectional and because of well-established agricultural input and output markets, we see no reason for the farmers in our sample to face varying price uncertainty. Thus, only yield uncertainties vary across the sample, and are modeled in this study. This observation provides important guidance in specifying the empirical model as it implies that the adoption premiums should

4 Readers familiar with the contingent valuation literature will immediately see the similarity between this model and the Cameron bid function approach commonly used to estimate the willingness to pay for an environmental quality change from discrete choice data (Cameron 1988). In the contingent valuation models, the bid offered to respondents in the survey varies across respondents in the same way that the expected net returns from conventional tillage will vary across a sample of farmers. It is this variability that allows identification of the variance of the error in both types of application.

depend on variables related to yield uncertainty as well as farmer characteristics that may define how uncertainty translates into adoption premiums. Since the expected net return π_1 does not depend on the uncertainty, σ_1^2 does not enter the explanatory variables **x**. Again, the connection of the premium to uncertainty in returns provides the theoretical foundation for separating the premium from net returns in the estimation model.

Not being able to account for price uncertainty may lead to biased predictions, but we suspect that the magnitude of the bias will likely be low for two reasons. First, as we show later on, the effect of the payoff uncertainty on the adoption premium can be captured almost entirely by that of the yield uncertainty. Second, price uncertainty affects the payoffs under both tillage practices. Its effect on the adoption premium would thus be determined by the *difference* between the two expected yields. Since the difference is low relative to the absolute levels of the yields, the premium due to price uncertainty is also likely to be low.

To sum up, we propose a new approach to econometric modeling of the decisions on adoption of alternative farming practices. Similarly to conventional approaches, the adoption is modeled as a discrete choice based on the relative profitability of alternatives and the resulting econometric model can be estimated as logit or probit, depending on the assumptions on the distribution of error terms. The novelty of the approach lies in recognition of the existence of a premium associated with risk aversion and/or option values and adept use of the data on (i) net returns under one of the alternatives and (ii) variability of net returns to recover (a) all the model parameters completely as opposed to up to a multiplier under conventional approaches and (b) the risk premium.

3. Data and Notation

The study region consists of the state of Iowa. The primary data source is a random sample drawn from the National Resource Inventory (NRI) (USDA/NRCS 1994). The data are statistically reliable for national, state, and multi-county analysis of non-federal land (Nusser and Goebel 1997). Thus, it is reasonable to assume that the Iowa NRI sample is representative of Iowa agricultural land. For the purposes of our estimation we treat each NRI point as representing a producer with a farmland homogeneous in weather, soil, landscape, crop rotation, and management system characteristics.[5] The area represented by each NRI point in the sample ranges from a hundred to several thousand acres with an average of just above 1,700 acres. Summary statistics and definitions of the explanatory variables are given in Table 1. All data are for the 1992 growing season.[6] The crops in the analysis are corn, soybeans, wheat, and hay.

Only one tillage system, either conservation or conventional, is reported for the entire NRI point. We assume that the producer has adopted conservation tillage if conservation tillage use is reported for the corresponding NRI point The tillage is defined as conservation if at least 30 percent of the soil surface is covered by plant residue after planting or at least 1,000 pounds per acre of flat small grain residue equivalent are on the surface during the critical erosion period (USDA/NRCS 1994). As seen from Table 1, 63% of Iowa cropland is worked using conservation tillage.

[5] Thus, the model is formulated and estimated at the per-acre level. This feature of data used requires an implicit assumption that the net returns to the two tillage practices, as well as the adoption premium, are independent of scale of adoption. (We thank an anonymous reviewer for contributing this observation.) A larger scale of adoption may reduce uncertainties about conservation tillage, due, for example, to adopters learning from each other. Since conservation tillage is adopted at a very high level in Iowa, the estimated premium in this paper may be an under-estimate of the premiums in other states where adoption occurs at a smaller scale.

[6] Unfortunately, the 1997 and later NRI's did not collect information on tillage practices; hence, more recent NRI data is not available for model estimation.

The NRI provides information on the natural resource characteristics of the land (soil properties and slope) and the crop grown (1992 and 1991 seasons). Because an increase in the amount of crop residue cover on the soil surface tends to keep soils cooler, wetter, less aerated, and denser, conservation tillage is favored on sloping and better-drained soils (e.g., Allmaras and Dowdy 1985). To account for this effect, the list of explanatory variables includes slope, soil permeability, and soil available water capacity. A positive relationship between slope and the probability of conservation tillage would be consistent with earlier studies of Rahm and Huffman 1984, Norris and Batie 1987, Wu and Babcock 1998, and Uri 1998.

To form our complete data set, we supplement the NRI data with constructed net returns to conventional tillage, climate, and farm operator characteristics data. We constructed $\bar{\pi}_0$ of each NRI sample point through farm budget analysis, specifically by combining county-specific average yield data (USDA/NASS 1994)[7], state-specific price data in 1992 (USDA/NASS 1999a), and the region-, tillage-, and rotation-specific cost data from Mitchell (1997). As shown in Table 1, when calculating $\bar{\pi}_0$, we grouped together the crops other than corn and soybeans to account for the somewhat idiosyncratic nature of these crop choices (over 90% of Iowa farmland is planted in corn or soybeans). The variable I_j is an indicator function for crops, j=cn (corn), sb (soybeans), oth (other), with I_j =1 if crop j is grown and I_j = 0 otherwise.

To put together climatic data for the crop growing seasons (as reported in USDA/NASS 1997), we assigned each NRI point to a weather station based on the county of location, and used 1975-1994 weather station data provided by the National Climatic Data

[7] Specifically, the county average yield data from 1975 to 1992 were used to estimate a linear time trend model. The resulting predictions for the year 1992 were taken as the expected yield (Wu, 2000).

Center (Earthinfo 1995) to construct temperature and precipitation data (TMAX, TMIN, PRECIP, and σ^2_{precip}). The intertemporal variance of precipitation σ^2_{precip} was calculated as the variance of the daily precipitation during the growing season over the years 1975-1994. Thus, it captures both the within season and cross season variations.

In accord with previous conservation tillage adoption studies, we included a number of farm operator and farm characteristics hypothesized to affect adoption decisions in the literature (Sunding and Zilberman 2000). County average indicators of farm operator characteristics (OFFFARM, TENANT, AGE, and MALE) were constructed from the 1992 Census of Agriculture data (USDA/NASS 1999b). [8] We consider the effect of *off-farm employment* in accord with Korsching et al. (1983), who found a higher, though statistically insignificant, off-farm employment involvement by adopters of minimum tillage in Iowa in 1980, and Fuglie (1999), who analyzed a sample of Midwestern farmers observed in 1991-1992, and similarly found a higher adoption of no-till by farmers working off-farm.

We also consider *tenancy*, the effect of which on adoption has been found to be mixed (see, for example, Fuglie 1999, and the discussion in Soule et al. 2000). Soule et al. (2000) point out that lease arrangements may influence renters' conservation decisions, and find that cash-renters are less likely than owner-operators to use conservation tillage, but share-renters are not. Share-renters, they explain, may behave more like owner-operators than cash-renters because they only bear a share of the costs and landlords tend to participate more actively in the management of farms rented under share leases.

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[8] We do not have data on farmer's education, a factor sometimes considered as affecting the adoption decisions. The AGE variable turned out to be highly correlated with another variable available in the Census of Agriculture, PRESENCE, the average years present on the farm (coefficient of correlation 0.67 with a p-value of less than 0.0001). The model estimated with the PRESENCE variable is neither quantitatively nor qualitatively different from the model with AGE, and is not presented here.

Age and *experience* are additional farmer characteristics the impact of which is commonly analyzed in the literature, albeit without agreement on the direction of the effect. Rahm and Huffman (1984) observed a positive, though statistically insignificant, association between human capital and adoption of conservation tillage for Iowa farmers growing corn in 1977. Fuglie (1999) found a positive effect of the years of farming experience on the adoption of reduced till in the Corn Belt in 1991-1992. Uri (1998) used 1987 farm-level data and found no statistically significant effect of age on adoption of conservation tillage. Korsching et al. (1983) surveyed farmers in three central Iowa watersheds in 1980 and found that adopters were younger on average than nonadopters. Norris and Batie (1987) found a statistically significant negative effect of age on conservation tillage acreage of cotton producers in Virginia. Featherstone and Goodwin (1993) found that farmers who are older invested less in conservation improvements. Finally, Soule et al. (2000) found a statistically significant negative effect of age on the adoption of conservation tillage by corn producers.

The consensus in the literature on the *gender effect* is that women are in general more risk averse than men (e.g., Jianakoplos and Bernasek 1998, and Barsky et al. 1997). Thus, one would expect the risk premium to be smaller for men than for women.

4. Empirical Model

We estimated several models that are variations of the following basic specification based on the conceptual model (3):

$$\Pr\left[adopt\right] = \Pr\left[\pi_1 \geq \overline{\pi}_0 + P + \sigma_\varepsilon \varepsilon\right] = \Pr\left[\varepsilon \leq \frac{\boldsymbol{\beta}\mathbf{x}}{\sigma_\varepsilon} - \frac{\overline{\pi}_0}{\sigma_\varepsilon} - \frac{\sigma^2_{precip}\boldsymbol{\alpha}\mathbf{z}}{\sigma_\varepsilon}\right], \quad (4)$$

where

$$\pi_1 = \mathbf{\beta x} = \beta_{0,cn} \cdot I_{cn} + \beta_1 \cdot SLOPE + \beta_2 \cdot PM + \beta_3 \cdot AWC + \beta_4 \cdot TMAX + \beta_5 \cdot TMIN + \beta_6 \cdot PRECIP$$
$$+ \beta_7 \cdot TENANT + \beta_8 \cdot OFFFARM + \beta_9 \cdot AGE + \beta_{10} \cdot MALE,$$

and

$$P = \sigma^2_{precip} \mathbf{\alpha z} = \sigma^2_{precip} \sum_{j=cn,sb,oth} I_j (\alpha_{1,j} + \alpha_{2,j} \cdot \bar{\pi}_0$$
$$+ \alpha_{3,j} \cdot OFFFARM + \alpha_{4,j} \cdot TENANT + \alpha_{5,j} \cdot AGE + \alpha_{6,j} \cdot MALE).$$

The *net returns* component, π_1, is modeled as a linear function of corn indicator (I_{cn}) as well as a number of factors that are affecting potential yields such as soil and landscape properties ($SLOPE$, PM, AWC) and climate measures ($TMAX$, $TMIN$, $PRECIP$). Farm and farmer characteristics are included as they may be related to the effort and/or ability to produce efficiently and achieve the potential yields. Notice that we model the *premium* term, P, as proportional to the weather variability. Agronomic studies indicate that a major variable that affects yield uncertainties under both conservation and conventional tillage is the variability of climatic conditions during a crop's growing season (Kaufmann and Snell 1997; Hansen 1991). In this study, we model the climatic variability via variability of precipitation. While the variability of temperature is also important, it often affects the yield variability in conjunction with precipitation variability (Runge 1968). Also, in our study region, areas with higher precipitation variability tend to have higher temperature variability during the crucial periods of the growing season; the sample correlation coefficients between precipitation variability and measures of temperature variability are as high as 0.25. Thus, only the precipitation variability is included in the premium estimation.

It is intuitive that such variability enters the premium under risk aversion. In the case of real options, a farmer facing higher weather variability has more incentive to gather information about how conservation tillage performs in the long run. A critical feature of conservation tillage is that the yield is more sensitive to weather conditions. Waiting may enable the farmer to observe (possibly from the neighbors or from county extension publications) the performance of conservation tillage under different weather conditions, and thus to update his information about the payoff. In other words, more sample points about π_1 are generated through waiting.

Note further that price uncertainty does not explicitly enter the premium equation. We exclude price uncertainty for two reasons. First, the market for corn and soybeans is rather homogeneous for the entire state, implying that farmers in our sample face similar price uncertainties. The effects of these uncertainties, however, cannot be identified due to the cross-sectional nature of our data. Second, even if we can identify their effects, price uncertainties are likely to constitute only a small part of the overall payoff uncertainties. Following McKinnon (1967), if yield and price are normally distributed, the payoff variance equals $\sigma_y^2[(1+\rho^2)\sigma_p^2+\mu_p^2]+2\rho\mu_p\mu_y\sigma_p\sigma_y+\mu_y^2\sigma_p^2$, where σ_y^2 and σ_p^2 are the variances, μ_y and μ_p are the expected values of yield and price, and ρ is the correlation coefficient between yield and price. Since the farm-level yields and prices are negatively correlated ($\rho<0$), the last two terms of the payoff variance have opposite signs. Moreover, the sum of the last two terms is relatively small: for the Iowa Sioux County data used in Hennessy et al (1997), we find that the last two terms account for 13.2% and 2.7% of the payoff uncertainty for corn and soybeans respectively. Thus, it is reasonable to ignore the last two terms of the payoff variance and assume that the standard deviation of revenue is proportional to the standard deviation of yield. In sum,

$$
\begin{aligned}
&\sigma^2_{payoff} \\
&= \sigma_y^2[(1+\rho^2)\sigma_p^2 + \mu_p^2] + 2\rho\mu_p\mu_y\sigma_p\sigma_y + \mu_y^2\sigma_p^2 \\
&\cong \sigma_y^2[(1+\rho^2)\sigma_p^2 + \mu_p^2] \\
&\sim \sigma^2_{precip},
\end{aligned}
$$

which is used to model the adoption premium as in (4).

The functional form assumed in (4) for the adoption premium guarantees that there is zero premium without the weather variability, as theoretically required. Specifically, the premium is specified as a product of the variance of precipitation and a crop-specific linear function of socio-economic variables.[9] Here, we use the net returns to conventional tillage as a proxy to farmer's income.[10] Notice that socio-economic characteristics may affect both the expected payoff of conservation tillage and the adoption premium, but with the inclusion of σ^2_{precip}, premium P is identified separately from profit π_1, separating the effects of those variables that affect both P and π_1.

The random variable ε is assumed to be logistically distributed, so model (4) is still a logit model. The parameters of interest, the β 's, the α 's, and σ_ε, are all estimated using the method of maximum likelihood.

Once model (4) is estimated, the subsidies that are needed to induce farmers to adopt conservation tillage are easy to calculate. Specifically, given the farmer, soil, and weather characteristics, the expected net return from conservation tillage, $\hat{\pi}_1$, can be predicted, along with the required adoption premium, $\hat{P}$. Let S be the minimum subsidy required for a farmer

[9] In this study, similarly to Wu et al. (2004), we implicitly assume that the choice of the crop grown is independent of and precedes that of the tillage decision. This seems to be reasonable for the region in question as according to NRI, more than 60% of Iowa cropland is under corn-soybeans rotation (USDA/NRCS 1994). For other regions, modeling the choice of crop and tillage simultaneously may be a better alternative.

to adopt conservation tillage. If a farmer has already adopted conservation tillage, the required subsidy is zero. Otherwise, the minimum subsidy must satisfy $\hat{\pi}_1 + S = \pi_0 + \hat{P}$. Then we know

$$S = \max\left\{\hat{P} + \left(\pi_0 - \hat{\pi}_1\right), 0\right\}. \tag{5}$$

When S is positive, it can be decomposed into two parts. One part (equal to $\hat{P}$) is used to remove the "hesitancy" of the farmer by compensating for his adoption premium, and the remaining part is the monetary transfer to compensate for the expected profit loss.

5. Results

5.1. Regression estimates

Unfortunately, there is high collinearity in the county-level farmer characteristics data. The presence of the problem can be seen from at least two indicators: high standard errors of coefficients when all variables in question are included in the model, and the moment matrix condition number, which is 78.85 for the (*OFFFARM*, *TENANT*, *AGE*, *MALE*) group.[11]

Several variations of the basic model (4) have been estimated; Table 2 contains the results for the specification we find most appealing. Specifically, we compared three models: (i) the unrestricted model (4) where the explanatory variables OFFFARM, AGE, and MALE appear in both the net returns (the β 's) and in the premium (the α 's), (ii) the restricted model in which the explanatory variables OFFFARM, AGE, and MALE appear in the net returns only, and (iii) the restricted model (reported) in which the explanatory variables OFFFARM,

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[10] The derivative of the probability of adoption with respect to $\overline{\pi}_0$ is proportional to:

$1 + \sigma_{precip} \cdot (\alpha_{2,cn} \cdot I_{cn} + \alpha_{2,sb} \cdot I_{sb} + \alpha_{2,oth} \cdot I_{oth})$.

[11] Belsley et al. (1980) argue that values above 20 suggest potential problems. We also considered including in the analysis an additional county-level variable, the average farm size, but that only worsened the collinearity problem as the moment matrix condition number for the (*OFFFARM*, *TENANT*, *AGE*, *MALE*, and *FARMSIZE*)

AGE, and MALE appear in the premium only. Using a generalized likelihood ratio test, we strongly reject model (ii) in favor of model (i) (the computed test statistic 42.6 is greater than the critical value of 21.67 at the 1% level of significance), and fail to reject model (iii) in favor of model (i) (the computed test statistic 2.64 is clearly less than the critical values at any conventional level of significance). Since results are very similar between models (i) and (iii), only the latter model is presented in Table 2 and discussed in the paper. [12] .

Estimates of the effect of soil and climatic conditions on the net returns to conservation tillage appear reasonable: land slope (the amount of inclination of the soil surface from the horizontal expressed as the vertical distance divided by the horizontal distance), soil permeability (the rate at which water can pass through a soil material), and available water capacity (the amount of water that a soil can store in a form available for plant use) are all positively related to better drainage of the soil. Improved soil drainage, in turn, is found to positively affect yields under conservation tillage systems (see for example Allmaras and Dowdy 1985). The effect of climatic variables on conservation tillage adoption is likewise consistent with agronomic science. The signs of the two temperature variables indicate that net returns are higher when the daily temperature variation is higher. The positive effect of precipitation is consistent with rainfall generally acting as a limiting factor of crop production.

The premium component was found to be statistically different from zero as the generalized likelihood ratio test strongly rejects the null hypothesis $H_0 : \alpha_j = 0$ for all j . The

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group is 104.75. The results for models that include FARMSIZE variable are similar to those reported and are not presented here for the sake of brevity.

[12] Several other alternative model specifications were considered but found to provide inferior fits. Specifically, the intercept term, β_0 , was initially allowed to vary for every crop, but the estimates were not significant for soybeans and for other crops. We also initially modeled the error term as heteroscedastic across crops, but the generalized likelihood ratio test failed to reject the hypothesis that the error term is homoscedastic. The computed test statistics, 6.56, does not exceed the critical value of 9.21 at the 1% level of significance.

computed test statistics is 177.8. In addition, restricting the premium component to zero would result in reducing the fraction of correct predictions by 8, percentage points.

While the county-level data available for this study is too aggregated in nature to make strong conclusions about the relationship between the social economic variables and adoption behavior, a few relationships are worth noting. *Farmer's age* is found to negatively affect the adoption premium, and thus to positively affect the adoption of conservation tillage. Previous studies have yielded mixed and inconclusive results on the effect of age and experience on adoption (see Rahm and Huffman 1984; Fuglie 1999; Uri 1998; Korsching et al 1983; Norris and Batie 1987; Featherstone and Goodwin 1993; and Soule et al. 2000). These mixed results may be due to the possibility that age affects risk aversion and option values differently. In particular, risk aversion, and consequently risk premium, has been shown to rise with age (Bakshi and Chen 1994, and Palsson 1996). The risk aversion argument has often been supplied as an explanation for the estimated negative effect of age on the adoption of new uncertain technologies (e.g., Dimara and Skuras 1998). However, if age is positively related to accumulated knowledge and experience about the suitability of conventional and/or conservation till, a farmer of older age may have less incentive to gather further information. Our estimation results suggest that the option value effect of age does indeed dominate the risk aversion effect.

Off-farm employment is found to reduce the adoption premium, thereby increasing the adoption rate, which is consistent with previous empirical research (Korsching et al. 1983, Fuglie 1999). Since those working off-farm have more diversified sources of income, they may be less risk averse and demand a smaller premium for adoption. Our estimates suggest a negative effect of the *proportion of males* on the adoption premium, which is consistent with the presumption that women are more risk averse. A higher rate of adoption of soil conservation structures by male operators was also estimated by Young and Shortle (1984).

We find that *tenancy* increases the expected net returns to conservation tillage, but also raises the adoption premium. Its overall effect on adoption is negligible as these two effects roughly cancel each other out. Thus, our estimates suggest an additional explanation for the mixed effects of tenancy not previously discussed in empirical literature: the relative dominance of either the effect of payoff or of the premium.

The *returns to conventional tillage* was used as a proxy to farmer's income in the analysis of the premium. The estimated strong negative effect of this variable on the premium is consistent with the presumption of decreasing absolute risk aversion that has found support in many studies of farmers' behavior (Moschini and Hennessy 2000). However, similar to the effect of tenancy, the overall effect of this variable on the probability of adoption is about zero at the data means.

5.2. Adoption Premiums and Subsidies

Table 3 presents the sample averages of estimated adoption payoffs and premiums. We apply the methodology of Krinsky and Robb (1986) to generate the confidence bounds on the estimates. This is a bootstrap-like procedure that uses the variance-covariance matrix estimates to generate a distribution of parameter values that reflects the model uncertainty. Specifically, the approach of Krinsky and Robb (1986) builds on the idea that the maximum likelihood estimators of model (4) are asymptotically unbiased and distributed as multivariate Normal random variables. Therefore, random draws from the multivariate Normal distribution with the mean equal to the estimates of the model parameters and variance equal to the estimated variance-covariance matrix of the parameters can be treated as the draws from the multivariate distribution of the parameters of the model. With a large number of draws, Monte-Carlo techniques can be used to describe the distributions of any smooth functions of the parameter estimators, including the premium, expected net returns to conservation tillage, and the subsidy needed for adoption. To obtain the estimates reported in Tables 3 and 4, we first draw randomly from the distribution of the model (4) parameter estimators, generate the quantities of interest for each sample point, and compute the sample averages. We then repeat the process for 10,000 draws and summarize the resulting empirical distributions.

As can be seen from Table 3, the premium, reported in the first line of the table for corn and the fourth for soybeans, accounts for about 13% of the annual expected returns to conventional tillage for both major crops (also reported in the table). This represents the amount that farmers would need to be paid to compensate them for the uncertainty associated with conservation tillage. If the net return to conservation tillage is greater than the premium, a farmer will adopt with no subsidy. If however, the net returns are negative, or less than the premium, a subsidy would be required for adoption.

Table 4 presents estimates of the premium and mean subsidy evaluated for the sub-sample of farmers who have not adopted conservation tillage and therefore are not predicted to adopt without any government subsidy. On average, consistent with the extensive agronomic studies, the expected profit of conservation tillage is *higher* than that of conventional tillage. For example, the predicted profit *gain* of conservation tillage is $5 per acre for corn and $28 per acre for soybeans.[13] Then what is the reason that such a farmer has not adopted conservation tillage in spite of the profit gains? The answer lies with the adoption premium.

[13] Of course, there are farmers for whom the expected net returns are lower under conservation tillage. They will not adopt even if their adoption premiums are zero.

The premium is $9 per acre for corn and $34 for soybean, both being higher than the profit gain from conservation tillage. Therefore, either because of risk aversion or real options, the farmer stayed with conventional tillage. That is, the potential gain was not high enough to offset the presence of risk aversion and/or real options.

The average subsidy needed to induce adoption, which equals the difference between the profit gain and the adoption premium (equation (5)), is $4.1 per acre per year for corn and $6.1 for soybean. Our estimate of the required subsidy is much lower than that estimated by Cooper (1997) (about $23). Our lower estimates seem reasonable in our study application given that, without any subsidies, about 64% of Iowa crop land under corn and 68% of that under soybeans is already worked using conservation tillage. Likewise, the subsidy estimates reported here are lower than those reported in Pautsch et al. (2001) due to our more accurate inclusion of a premium and better econometric fit.

Applying equation (5) to each sample point, we calculate the required minimum adoption subsidies for the entire sample and obtain the state's intensity of adoption at each subsidy level, or the "supply curve" of conservation tillage, presented in Figure 1. Over 14 million acres (about 63% of all agricultural land in Iowa) were already in conservation tillage without any subsidy for the year of the study. The acreage increases as the subsidy level rises. At a subsidy of $19.5 per acre, the model predicts that about 90% of farmland will be in conservation tillage. Note that the use of the econometrically estimated model allows estimation of the confidence bounds on the estimated supply curve and the subsidy needed to achieve any given level of adoption. Similarly to the results reported in Tables 3 and 4, the confidence bounds in Figure 1 are obtained from 10,000 random draws using Krinsky and Robb (1986) methodology.

The supply curve allows us to analyze the nature of a conservation tillage subsidy, in particular its role as a tool for environmental efficiency or for income transfer. Suppose the government decides to subsidize conservation tillage at $19.5 per acre, for new and existing adopters alike. The subsidy acts as a pure income transfer for existing adopters, for they do not need any additional incentive to adopt. Even for the new adopters, part of the subsidy is in fact an income transfer (similar to producer surplus) due to the heterogeneity of the adoption costs. Only the area under the supply curve captures the required compensation for conservation tillage, or serves the single purpose of generating environmental benefits from conservation tillage.

From Figure 2, it is obvious that the income transfer portion of the subsidy far exceeds the efficiency payment component. Of the $390 million total subsidy needed to achieve 90% adoption, some $52 million are the social costs, i.e. the subsidy used to induce the adoption that would have not happened in the absence of subsides. About $338 million, or over 86% of the total subsidies, are income transfers, a major part of which goes to existing adopters. The 95 percent confidence interval for the total subsidy is estimated to be [226, 586] million dollars, and that for the income transfers is [194, 509] million dollars.

5. Conclusion

In this paper, we propose a method for directly estimating the financial incentives for adopting conservation tillage and distinguishing between the expected payoff and premium of adoption based on observed behavior. We find that the adoption premium may play a significant role in farmers' adoption decisions. Some non-adopters do not use conservation tillage because the expected profit gain alone does not fully compensate them for the increased risk and possibility of irreversible lost profits associated with conventional tillage practices. To induce adoption, government subsidies could be used to overcome the adoption premium net of the expected gain from adoption. We find that on average the mean annual subsidy that would have been needed in 1992 in Iowa is $4.1 per acre for corn and $6.0 for soybeans. Further, if uniform subsidies are paid to both current and new adopters, transfer costs could exceed 85% of the program expenditures.

Several important caveats to these magnitudes are important. First, the government may choose to subsidize new adopters only, although the political feasibility of such a policy is an open question, as some have argued that it punishes “good stewards” of farmland. This would however, significantly reduce the program costs. Second, it may become feasible to reduce or eliminate payments to some farmers over time as the reticence to adopt due to option values or risk declines with experience and comfort with this technology.

Information on the estimated adoption subsidy should be helpful to policymakers interested in designing subsidy programs for environmentally friendly agricultural practices. Specifically, the CSA of the 2002 U.S. farm bill pays farmers in selected watersheds to adopt environmentally friendly practices. The estimates provided here can be directly applied to identifying conservation payments to achieved targeted adoption rates. Further, the methodology developed, given appropriate data, could be directly applied to other practices or bundles of practices such as drip irrigation, terracing, buffer strips, etc., to provide additional policy-relevant information. The model can be also be applied to situations where the expected net returns to both alternatives under consideration (and, consequently, the difference in the net returns) are assumed known to farmers.

In this paper, we do not distinguish between the risk aversion and real options forces underlying the adoption premium. However, the distinction is important for policy design because the two possibilities may suggest different optimal policy responses. For example, if it is risk aversion that generates the bulk of the premium, a proper government response may be to offer stabilization policies such as green insurance. However, if it is irreversibility of sunk investments that primarily generates the premium, measures to reduce the option value are more efficient, such as providing better information about conservation tillage or reducing the sunk cost of adoption (e.g., by subsidizing conservation tillage in early years). It would also be of interest to identify and analyze any changes in the premium over time when newer data become available. There are a number of changing conditions that are likely to affect the willingness to adopt conservation tillage in the absence of subsidies that could change the estimates from our model over time, including improved conservation tillage technology and machinery, changing fuel prices, and changing attitudes about "green" farming practices.[14]

Finally, another distinction not explicitly addressed in this model is the use of continuous conservation tillage vs. the adoption of conservation tillage for a single year. For some environmental amenities, notably carbon sequestration, a break in the use of conservation till will dissipate many of the accumulated benefits; thus, lower compensation for farmers willing to commit to a single year of conservation tillage may be appropriate with correspondingly higher compensation for those willing to commit to a longer term. An explicitly dynamic model would be needed for examining this issue.

[14] We thank an anonymous reviewer for making this point.

Table 1. Definition of Variables and Summary Statistics [i]

Notation	Description	Units	Sample Mean	Sample St. Dev.
	Conservation tillage (1-yes, 0-no)	Number	0.63	0.48
I_{cn}	Corn (1-corn, 0-soybeans or other crop)	Number	0.57	0.50
I_{sb}	Soybeans (1-soybeans, 0 - otherwise)	Number	0.35	0.48
I_{oth}	Other crops (0-corn or soybeans, 1 – otherwise)	Number	0.08	0.27
$\overline{\pi}_0 \cdot I_{cn}$	Net returns to conventional tillage, corn [ii]	$ per acre	145	23
$\overline{\pi}_0 \cdot I_{sb}$	Net returns to conventional tillage, soybeans [iii]	$ per acre	109	14
$\overline{\pi}_0 \cdot I_{oth}$	Net returns to conventional tillage, other crops [iv,v]	$ per acre	93	43
SLOPE	Land slope	Percent	4.1	3.9
PM	Soil permeability	Inches per Hour	1.7	2.2
AWC	Soil available water capacity	Percent	18.4	2.8
TMAX	Mean of daily maximum temperature during the corn growing season	Fahrenheit	78.7	1.8
TMIN	Mean of daily minimum temperature during the growing season	Fahrenheit	55.6	2.0
PRECIP	Mean of daily precipitation during the growing season	Inches	0.141	0.012
σ^2_{precip}	Variance of daily precipitation during the growing season	Inches^2	0.110	0.018
OFFFARM	Proportion of operators working off-farm to the total number of farm operators in the county	Number	0.471	0.055
TENANT	Proportion of harvested cropland operated by tenants to the total county harvested cropland	Number	0.199	0.050
AGE	County average farm operator age	Years	50.2	1.8
MALE	Proportion of male operators to the total number of farm operators in the county	Number	0.9774	0.0096

[i] 1,336 observations
[ii] summary statistics are for 762 non-zero observations
[iii] summary statistics are for 475 non-zero observations
[iv] wheat, or hay
[v] summary statistics are for 99 non-zero observations

TABLE 2. Maximum Likelihood Estimates of the Adoption Model[i]

Variable(s)	Parameter	Estimate
Net returns to conservation		
I_{cn}	$\beta_{0,cn}$	37.1*
		(9.0)
SLOPE	β_1	0.36***
		(0.19)
PM	β_2	0.99**
		(0.49)
AWC	β_3	1.16*
		(0.45)
TMAX	β_4	3.71*
		(0.92)
TMIN	β_5	-4.0*
		(1.1)
PRECIP	β_6	84
		(107)
TENANT	β_7	126
		(93)
Error term multiplier	σ_ε	10.1*
		(2.4)
Premium		
$\sigma^2_{precip} \cdot I_{cn}$	$\alpha_{1,cn}$	6446*
		(1873)
$\sigma^2_{precip} \cdot I_{sb}$	$\alpha_{1,sb}$	5532*
		(2054)
$\sigma^2_{precip} \cdot I_{oth}$	$\alpha_{1,oth}$	7736**
		(3501)
$\sigma^2_{precip} \cdot \overline{\pi}_0 \cdot I_{cn}$	$\alpha_{2,cn}$	-7.70*
		(0.54)
$\sigma^2_{precip} \cdot \overline{\pi}_0 \cdot I_{sb}$	$\alpha_{2,sb}$	-10.8*
		(1.0)
$\sigma^2_{precip} \cdot \overline{\pi}_0 \cdot I_{oth}$	$\alpha_{2,oth}$	-12.5*
		(2.3)
$\sigma^2_{precip} \cdot TENANT \cdot I_{cn}$	$\alpha_{3,cn}$	1158
		(845)
$\sigma^2_{precip} \cdot TENANT \cdot I_{sb}$	$\alpha_{3,sb}$	1687**
		(775)
$\sigma^2_{precip} \cdot TENANT \cdot I_{oth}$	$\alpha_{3,oth}$	831
		(1220)
$\sigma^2_{precip} \cdot OFFFARM \cdot I_{cn}$	$\alpha_{4,cn}$	-570**

		(232)
$\sigma^2_{precip} \cdot OFFFARM \cdot I_{sb}$	$\alpha_{4,sb}$	-615**
		(275)
$\sigma^2_{precip} \cdot OFFFARM \cdot I_{oth}$	$\alpha_{4,oth}$	-403
		(497)
$\sigma^2_{precip} \cdot AGE \cdot I_{cn}$	$\alpha_{5,cn}$	-26.2*
		(8.4)
$\sigma^2_{precip} \cdot AGE \cdot I_{sb}$	$\alpha_{5,sb}$	-24**
		(10)
$\sigma^2_{precip} \cdot AGE \cdot I_{oth}$	$\alpha_{5,oth}$	-63***
		(34)
$\sigma^2_{precip} \cdot MALE \cdot I_{cn}$	$\alpha_{6,cn}$	-3941*
		(1466)
$\sigma^2_{precip} \cdot MALE \cdot I_{sb}$	$\alpha_{6,sb}$	-3177***
		(1683)
$\sigma^2_{precip} \cdot MALE \cdot I_{oth}$	$\alpha_{6,oth}$	-3003
		(2540)
Fraction of correct predictions		0.71
Log (likelihood)		-776.5

[i] Standard errors are reported in parenthesis; they are computed from analytic second derivatives; *, **, and *** indicate statistical significance at the 1%, 5%, and 10% levels respectively.

TABLE 3. Estimated Per Acre Adoption Payoff and Premium: Sample Averages [a]

Variable	5th Percentile	Median	95th Percentile
Corn			
Premium, $\hat{P}$, dollars	-1.4	14.4	30.3
Expected net returns to conservation tillage, $\hat{\pi}_1$, dollars	149.2	166.1	183.1
Percentage of the premium in the expected net returns to conventional tillage, $\hat{P}/\overline{\pi}_0$, percent	1.0	12.3	23.6
Soybeans			
Premium, $\hat{P}$, dollars	-4.7	12.0	28.6
Expected net returns to conservation tillage, $\hat{\pi}_1$, dollars	111.5	129.3	146.8
Percentage of the premium in the expected net returns to conventional tillage, $\hat{P}/\overline{\pi}_0$, percent	-2.9	12.9	28.3
Other Crops			
Premium, $\hat{P}$, dollars	11.7	34.1	56.1
Expected net returns to conservation tillage, $\hat{\pi}_1$, dollars	102.3	121.8	140.8
Percentage of the premium in the expected net returns to conventional tillage, $\hat{P}/\overline{\pi}_0$, percent	31.5	62.0	92.0

[a] The estimates are the summaries of 10,000 draws from the respective numerical distributions. The draws are obtained using the Krinsky and Robb (1986) methodology.

TABLE 4. Estimated Per Acre Adoption Premium and Subsidy: Averages for Current Non-Adopters [a]

Variable	5th Percentile	Median	95th Percentile
Corn			
Profit loss due to adoption, $\bar{\pi}_0 - \hat{\pi}_1$, dollars	-22.6	-5.3	11.8
Premium, $\hat{P}$, dollars	-8.0	9.4	27.4
Subsidy needed for adoption, $\hat{S} = \hat{P} + (\bar{\pi}_0 - \hat{\pi}_1)$, dollars	2.7	4.1	5.8
Soybeans			
Profit loss due to adoption, $\bar{\pi}_0 - \hat{\pi}_1$, dollars	-48.0	-28.6	-7.8
Premium, $\hat{P}$, dollars	12.5	34.6	54.8
Subsidy needed for adoption, $\hat{S} = \hat{P} + (\bar{\pi}_0 - \hat{\pi}_1)$, dollars	3.5	6.0	8.7
Other Crops			
Profit loss due to adoption, $\bar{\pi}_0 - \hat{\pi}_1$, dollars	-44.2	-24.7	-4.7
Premium, $\hat{P}$, dollars	15.6	38.9	62.1
Subsidy needed for adoption, $\hat{S} = \hat{P} + (\bar{\pi}_0 - \hat{\pi}_1)$, dollars	8.8	14.1	20.1

[a] The estimates are the summaries of 10,000 draws from the respective numerical distributions. The draws are obtained using the Krinsky and Robb (1986) methodology.

Figure 1. Conservation tillage supply curve and the subsidy needed to achieve 90% adoption with 95 percent confidence bounds

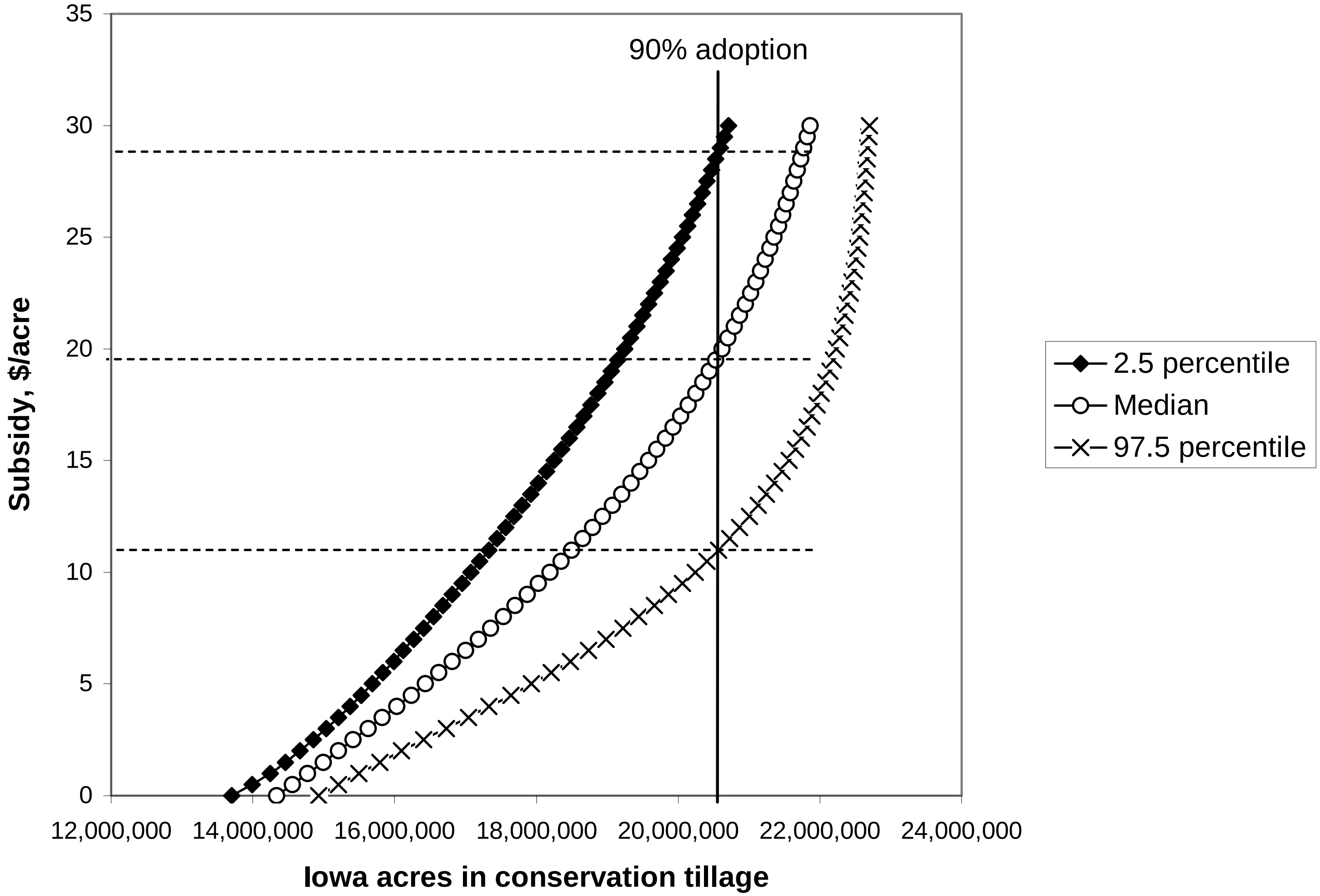
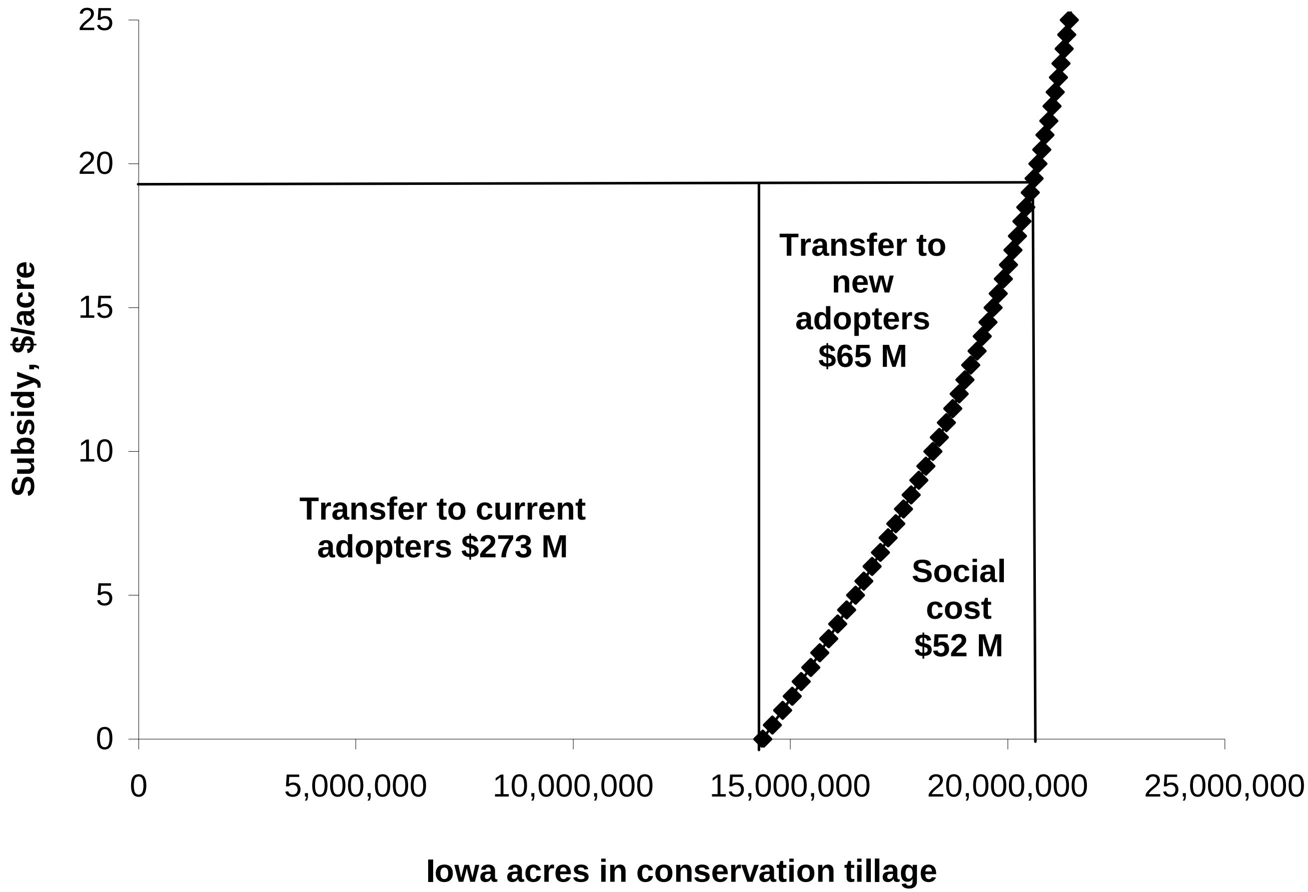


Figure 2. Total predicted cost to achieve 90% adoption in Iowa. Total cost = $390 M = $52 M + $65 M + $273M



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