# Estimating Farmers' Willingness to Change Tillage Practices to Supply Carbon Emissions Offsets

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## Abstract

One common element in many voluntary and regulatory carbon markets to date has been the inclusion of emissions offsets that can be sold by entities outside of emission caps. A particularly low cost means of sequestering atmospheric carbon is reducing tillage of agricultural soils. A choice experiment is conducted with corn and soybean farmers in Indiana, USA to measure farmers' willingness to change tillage practices to supply carbon offsets by estimating their willingness to accept (WTA) payment related to different attributes of active and proposed carbon markets. This research is unique in its focus on the supply side of the market for environmental services, and contributes to the nascent literature on the valuation of the 'means' of achieving an improvement in environmental quality, rather than the environmental 'end' result of a proposed policy or market. Understanding farmers' preferences and willingness to adjust practices is vital to designing schemes that farmers will participate in so that global carbon abatement efforts can be achieved in the most cost-effective ways possible. We investigate attribute non-attendance (ANA) in our sample, estimate and compare WTA amongst adopters and non-adopters of no-till, and compare WTA with current carbon prices to evaluate the prospects for increased adoption.

**Keywords** offsets, tillage, choice experiment, attribute non-attendance, climate change

**JEL code** Q12, Q24, Q51, Q54

Wide-reaching international agreements like the Kyoto Protocol have thus far failed to achieve the aggregate global greenhouse gas (GHG) emissions reductions agreed to by the international community because not all national governments ended up ratifying the original treaty. The result has been incomplete international implementation of climate change mitigation strategies. The European Union (EU) and a limited number of smaller countries that contribute relatively little emissions, but are negatively affected by climate change, have more or less adhered to the terms of the original agreement reached through the United Nations Framework Convention on Climate Change (UNFCCC). The failure of efforts to forge a binding international agreement to extend the Kyoto Protocol beyond 2012 has given way to a more decentralized approach to limiting global greenhouse gas emissions, under which several countries that were previously moving forward with GHG reduction plans have scaled back or canceled their plans to act. In Copenhagen in 2009, in Cancun in 2010 and in Durban in 2011, UNFCCC participants from a more limited set of countries committed to individualized emissions reductions (by the year 2020) relative to 2005 levels that allow for greater flexibility in establishing reduction targets and the metric used to quantify reductions.

The EU, a group of northeastern states in the United States (US) known as the Regional Greenhouse Gas Initiative (RGGI), New Zealand, the city of Tokyo, the Canadian province of Quebec, and the state of California are among the government entities that are implementing policies to reduce carbon emissions. Each city, state, country or regional entity in these schemes has different limits, means of compliance and mechanisms to incentivize emissions reductions. Both Alberta and British Columbia have enacted provincial carbon pricing schemes in Canada. The most recent legislative attempt to enact a national limit on carbon equivalent emissions in the United States failed in 2009, with the US House of Representatives passing the Waxman-

Markey bill (American Clean Energy and Security Act of 2009) that did not advance in the U.S. Senate; it would have capped emissions, allowed emissions trading, and allowed for the use of emissions offsets to comply with the declining emissions cap. The Obama administration has since taken a more traditional regulatory approach to GHG emissions reduction by mandating an increase in vehicle gas mileage using the Corporate Average Fuel Economy (CAFE) standards for vehicles sold in the US and introducing regulations to cap carbon emissions from electric utilities (Federal Register, 2014).

One policy component common to most carbon emissions limits and carbon pricing schemes enacted to date is the inclusion of emissions credits or certified emissions reductions (CERs), which are commonly referred to as "offsets," that can be used to comply with these policies. Offsets allow firms in those economic sectors covered by emissions limits or with carbon taxes imposed upon them to purchase emissions credits achieved by reducing emissions that are not limited by an emissions cap or subject to a carbon tax. Such credits can be generated many different ways, and protocols for crediting have been developed previously by the now-defunct voluntary Chicago Climate Exchange (CCX), the government of Alberta (http://environment.alberta.ca/02275.html), the state of California (http://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm), and the UNFCCC (http://cdm.unfccc.int/methodologies/index.html). Capturing or flaring methane emissions from landfills, capturing or destroying fluorinated gases (HFCs, PFCs, and $SF_6$), or sequestering carbon either before it is emitted or directly from the atmosphere are all examples of practices for which offset protocols could be developed in regulatory or voluntary carbon markets. Though implicitly allowed for under any policy that includes an offset or CER provision, specific protocols for agricultural soil carbon sequestration (ASCS) have only been implemented by the

CCX and Alberta schemes referenced previously. Previous economic research has examined different aspects of ASCS (Gramig, 2012 and cites therein).

The use of choice experiments (CE) to estimate willingness-to-pay (WTP) for environmental quality, attributes of recreational sites and reductions in morbidity or mortality risk is well known in the environmental economics literature. In agricultural economics, CEs have also been widely used to estimate consumer WTP for attributes of food products, and livestock products in particular. Different methods and experimental settings have been utilized including in-person interviews/auctions (Gracia, Loureiro and Nayga, 2009), some at point of purchase (Lind, 2007), mail surveys (Nilsson, Foster, and Lusk, 2006; Carlsson, Frykblom and Lagerkvist, 2007; Tonsor, Olynk and Wolf, 2009), phone surveys (Lusk and Norwood, 2008), and internet surveys (Olynk and Ortega, 2013; Wolf, Tonsor, and Olynk, 2011; Gao and Schroeder, 2009; Olynk, Tonsor and Wolf, 2010). While stated preference methods continue to be used to measure preferences on the demand side of the market in environmental economics, CEs are increasingly being conducted with farmers on the supply side of markets to investigate producers' willingness-to-change (WTC) management practices to supply ecosystem services from working agricultural land (Christensen, et al., 2011, Ma, et al., 2012) or satisfy consumer demand for credence attributes derived from the production processes used to grow a crop or raise livestock (Schulz and Tonsor, 2010). This research integrates valuation methods and brings these two threads of applied economic literature together by estimating producers' WTC the way they manage farm fields and how they tradeoff net revenue against attributes of ecosystem services procurement mechanisms to achieve environmental policy objectives.

A closely related article uses a CE to measure farmer preferences for an agri-environmental policy to incentivize planting of Nitrogen-fixing crops on marginal dryland in

Spain (Espinosa-Goded, et al., 2010). Other related research surveyed the general public about their preferences for the structure of agricultural land preservation based on the mechanism used, the level of pubic access to the preserved land and other attributes (Johnston and Duke, 2007). The current study similarly measures preferences for attributes of the *means* of achieving an environmental policy, rather than estimating the value individuals or households place on the policy *end*, as is normally the objective of non-market valuation of environmental resources or quality. As Espinosa-Goded, et al (2010) point out, agri-environmental policies will not be effective unless there is strong farmer participation. Separating the determinants of farmer willingness to consider participating in payment for environmental services schemes and the level of participation is the subject of another more recent article (Ma, et al., 2012). These issues are especially critical when talking about getting farmers to reduce or eliminate tillage in order to sequester atmospheric carbon in agricultural soils because those farmers who have not already adopted conservation tillage techniques are the ones who will have to be convinced to change their practices in order to satisfy what is referred to as additionality—new adoption of practices that farmers did not previously adopt or are not expected to adopt in the future in the absence of an offset market. Related survey-based experimental work has examined whether different ways of framing conservation tillage affects expressed farmer interest in the practice (Andrews, et al., 2013). Conservation tillage is of particular interest because of the large technical potential to expand use of the practice to sequester atmospheric carbon (Smith, et al., 2008) and its cost-effectiveness as a means of carbon abatement (McCarl and Schneider, 2001).

This research addresses a gap in the literature by investigating farmers' preferences for different attributes of prospective climate change policies and willingness-to-change production practices to supply emissions offsets to mitigate climate change. This study is relevant for policymakers and carbon market participants, and is novel in its focus on measuring preferences using a CE on the supply side of the carbon offset market. This study estimates producer willingness to adopt various tillage practices. The objectives of this analysis are:

1) To determine producer willingness to adopt reduced tillage practices and

2) Assess preferences for attributes of mechanisms to incentivize soil carbon sequestration.

These are both important research topics because of the low carbon abatement cost of conservation tillage and no-till, and because neither the UNFCCC nor the EU Emissions Trading Scheme (ETS) have developed soil carbon protocols for certified emissions reductions under the Kyoto Protocol or EU ETS. Development of policies or more detailed protocols themselves must be scientifically rigorous, but also must consider what contract terms, tillage practices and payments will be acceptable and/or attractive to farmers. Otherwise, further adoption of no-till to supply certified emissions reductions are unlikely. In order to assess farmers' WTC tillage practices, a CE was designed based on key attributes of different policy or market designs to pay farmers for sequestering atmospheric carbon in agricultural soils by reducing or eliminating tillage.

**Sampling Strategy, Survey Instrument and Experimental Design**

The target population for our survey is farmers with tillable acres in the US state of Indiana. Ideally this would mean drawing a random sample from a list of addresses for all farms with tillable acres in the state, but no such list is readily available. In an effort to obtain the largest list of farmer addresses possible, the researchers filed an electronic Freedom of Information Act (e-FOIA) request with the US Department of Agriculture for all federal farm subsidy recipients in the state of Indiana in 2009. Only names and addresses associated with a payment for either corn or soybean crops were retained, based on the assumption that the vast majority of productive, arable land in the state is used to grow these two crops. Eliminating duplicate addresses for those who received farm payments for both corn and soybeans left 47,107 unique addresses, which compared very favorably with the 46,373 corn and soybean farms reported in the most recent prior agricultural census (USDA-NASS, 2007). A simple random sample of 2,000 farmers was drawn from the address list to receive the survey. Table 1 details respondents' demographic information for those who completed the survey, revealing a very good match in terms of geographical distribution of farms across crop reporting districts and predictably over samples larger size farms relative to smaller farms.

A mixed-mode survey with paper or internet response options available was conducted following the methods in Dillman (2009) in between planting and harvest from July-September of 2010. There were five waves of contacts beginning with a standard invitation letter with a link to the web address where participants could respond online. Internet surveys are becoming more popular due to their low costs and speedy completion times (Louviere et al., 2008; Gao and Schroeder, 2009; Olynk, Tonsor and Wolf, 2010; Tonsor and Wolf, 2011; Olynk and Ortega, 2013). Hudson, et al. (2004) found that internet surveys did not exhibit nonresponse bias. Similarly, Fleming and Bowden (2009), as well as Marta-Pedroso, Freitas and Domingos (2007), found no significant differences when comparing results between web-based surveys, conventional mail and in-person interview surveys. When looking specifically at choice experiments, Olsen (2009) found no significant differences in mean WTP estimates between internet surveys and mail surveys. The intent of allowing online or paper responses was to get as many early online responses as possible and then be able to afford to send print surveys to additional randomly drawn addresses from the address list. This did not transpire because of low initial online response rates. After sending three printed surveys by mail, with a reminder postcard in between the first and second printed mailings, and eliminating bad addresses, the final response rate was 42 percent.

In addition to demographic questions and the CE, respondents were also asked questions about their beliefs related to climate change and the sources of information they receive about tillage (see Gramig, et al., 2013 for additional analysis). The survey instrument was developed after consulting many prior surveys of tillage practice adoption and adoption of other conservation practices. The authors consulted with the Conservation Technology Information Center (www.ctic.org), certified crop advisors that provide agronomic advise to farmers, tillage researchers and extension educators in selecting the language used in the survey. The instrument was piloted with 25 farmers and undergraduate and graduate students with farming backgrounds in the College of Agriculture at Purdue University during the fall 2009 semester.

*Choice Experiment*

A CE asks participants to select an option—a product for purchase or a recreational site to visit in the case of consumers, or a management practice in the case of producers—by evaluating the bundle of characteristics or attributes of each option. A CE mimicks real-world purchasing and production situations by allowing decision makers to tradeoff among the levels of different attributes in selecting from a set of alternative options. A CE was designed to elicit producers' preferences for different tillage practices and associated attributes of different mechanisms to incentivize broader adoption of reduced tillage systems. The choice sets allowed participants to choose between one of two reduced tillage alternatives or to select conventional tillage (the opt out option available in every choice set), based on the tillage practice and three additional attributes listed in Table 2: net revenue, the source of a carbon payment, and a multi-year contract requirement. Appendix A details the attribute definitions shown to survey respondents as part of the information treatment that accompanied the CE. The three different tillage practices were selected to include two forms of reduced tillage capable of achieving different levels of carbon sequestration (conservation tillage, and no tillage or no-till), and conventional tillage, which was the most widely used tillage practice in Indiana at the time the survey was conducted (ISDA, 2013). The second attribute was the increase in net revenue resulting from each alternative in a given choice set and included three levels: $0/acre, $5/acre, or $10/acre. Increases in net revenue were chosen to be consistent with market prices, the cost of tillage operations and crop yields at the time the survey was conducted. Because famers could potentially sell offsets on a cap-and-trade market or be paid to supply climate regulation ecosystem services through a government program more similar to a conservation cost-share program like the Environmental Quality Incentives Program (EQIP) in the US, a third attribute in the choice experiment is the source of a carbon payment: commodity market, government payment, or no payment is made to the farmer. The final attribute is whether or not a multi-year contract is required. The motivation for including this attribute is based on the few existing soil carbon sequestration protocols that have been developed which require a minimum number of years with reduced or no tillage being performed and the multi-year contracts required for existing USDA environmental cost-share programs. An example choice set can be found in Appendix B.

A main effects plus two-way interaction design was used to determine choice scenarios (Lusk and Norwood, 2005). The SAS *OPTEX* procedure was utilized to identify an experimental design maximizing D-efficiency (98.935). The final choice design resulted in 36 choice sets which were blocked into four groups of nine choice sets to keep the survey manageable for participants and reduce respondent fatigue (Tonsor et al., 2005; Olynk and Ortega, 2013). Therefore, each survey respondent was shown nine choice sets, each with two alternatives with varying levels of their attributes and a fixed conventional tillage option. The choice set order was randomized for online responses to mitigate any ordering effects (Loureiro and Umberger, 2007; Olynk, Tonsor, and Wolf, 2010), but this was not tractable for paper surveys.

Because hypothetical CEs are simulated choices and there is no actual exchange of money in this CE, the following instructions were given to participants:

> "It is important that you make your selections like you would if you were actually facing these choices in making farm management decisions."

This statement is part of a "cheap-talk" strategy to reduce hypothetical bias by informing participants of the context in which they should make the hypothetical choice before their participation in the choice experiment (Lusk, 2003).

## Theoretical Framework and Research Methods

### *Random Utility Theory*

Central to the idea of random utility theory is the assumption that economic agents seek to maximize their expected utility subject to the choice sets they are presented. Based on Manski (1977), an individual's utility is a random variable because the researcher has incomplete information. In random utility theory, utility ($U_{it}$) is obtained from selecting alternative $i$ from a finite set of alternatives contained in choice set $C$ in situation $t$. Therefore, utility can be characterized by the following equation:

$$U_{it} = V_{it} + \varepsilon_{it} \tag{1}$$

where $V_{it}$ is the deterministic portion of utility dependent upon the attributes of the alternative and $\varepsilon_{it}$ is the stochastic component of utility, which is independently and identically distributed over all alternatives and choice scenarios. An individual will select alternative $i$ if the utility from selecting $i$ is greater than the utility from alternative $j$, $U_{it} > U_{jt}$ $\forall$ $i \neq j$. Accordingly, the probability of selecting alternative $i$ is given by,

$$P_{it} = P(V_{it} + \varepsilon_{it} > V_{jt} + \varepsilon_{jt},) \; \forall \; i \neq j, \forall \; j \in C. \tag{2}$$

The probability that alternative $i$ is selected is

$$P_{it} = \frac{e^{\mu V_{it}}}{\sum_{j \in C} e^{\mu V_{jt}}}, \tag{3}$$

where $\mu$ is a scale parameter which is inversely related to the variance of the error term (Lusk, Roosen, and Fox, 2003; Olynk, Tonsor, and Wolf, 2010).[1]

Under the assumption that the systematic portion, $V_{it}$, is linear in parameters, the specification of the general model can be expressed as

$$V_{it} = \beta_1 x_{it} + \cdots + \beta_k x_{it} , \tag{4}$$

where $x_{it}$ is a vector of attributes found in the $i^{th}$ alternative, and $\beta$s are parameters associated with the attributes of the $i^{th}$ alternative.

Multinomial logit models assume that individuals have homogeneous preferences for the product attributes; however, this assumption will not hold if individuals possess heterogeneous preferences, as suggested by recent literature that has used CE to evaluate farmer preferences (Schulz and Tonsor, 2010; Olynk, Tonsor and Wolf, 2010). Therefore, employing a model that allows for heterogeneous preferences is appropriate (Lusk, Roosen, and Fox, 2003; Alfnes, 2004; Tonsor et al., 2005).

*Random Parameters Logit*

The random parameters logit (RPL) model, also called the mixed logit model, allows respondent preferences to be heterogeneous. Through the use of the RPL model we are able to directly estimate this heterogeneity across the evaluated attributes. In the RPL model, the random utility ($U_{nit}$) of attribute $i$ of individual $n$ in situation $t$ is

$$U_{nit} = v_{nit} + [u_{ni} + \varepsilon_{nit}] , \tag{5}$$

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[1] Similar to other recent works, the scale parameter, $\mu$, was assumed to be equal to one because it is unidentifiable in any given dataset (Lusk, Roosen, and Fox, 2003; Olynk, Tonsor, and Wolf, 2010).

where $v_{nit}$ is the systematic portion of the utility function, $u_{ni}$ an error term which is distributed normally over individuals and attributes (but not choice sets) and $\varepsilon_{nit}$ is the stochastic error that is independently and identically distributed over individuals, attributes and choice sets.

The subsequent model for the systematic portion of utility on choice occasion *t* is:

$$v_i = \beta_1 NetRev_i + \beta_2 Tillage_i + \beta_3 Conv_i + \beta_4 Contract_i + \beta_5 Govt_i + \beta_6 CAT_i \ . \quad (6)$$

*NetRev* is the increase in net revenue shown to respondents in the choice set. *Tillage* is an effects coded variable which equals one for conservation tillage and negative one for no-till, and *Conv* is a constant used to describe the utility associated with opting for conventional tillage rather than either of the two reduced tillage options. *Contract* is an effects coded variable indicating whether or not a multi-year contract is required by the alternative. The remaining two variables are dummy coded with *Govt* indicating a carbon payment received from the government and *CAT* indicating a carbon payment received from a cap-and-trade (CAT) market; the reference case (*Govt* = *CAT* = 0) is no carbon payment received from the government or a CAT market. Interaction terms with demographic and behavioral variables that were included in the experimental design were also considered but not included in the final model because none were found to be statistically significant.

It is hypothesized that farmers may have positive or negative preferences towards any of the attributes investigated. In order to allow WTP estimates to be either positive or negative, the random parameters **β** were assumed to be drawn from a normal distribution (Lusk, Roosen, and Fox, 2003; Tonsor et al., 2005); the coefficients on all explanatory variables except *NetRev* were specified to vary normally across farmers. Because RPL does not exhibit the independence from irrelevant alternatives property of the standard logit model, general patterns of correlated taste parameters can arise (Revelt and Train, 1998). Let **β** be defined as a *k* x 1 vector of all the attribute coefficients, η a

($k$-2) x 1 vector of the random attribute coefficients found in β and specify $\eta \sim N(\bar{\eta}, \Omega)$. The resulting random coefficient vector is expressed as $\eta = \bar{\eta} + LM$ where $L$ is a lower triangular Cholesky factor of Ω such that LL' = Ω, and **M** is a vector of independent standard normal deviates (Revelt and Train, 1998). The data is supportive of dependence in tastes and the model allows for a better understanding of correlations in preferences across attributes if some of the estimates of the Cholesky matrix Ω show statistical significance (Scarpa and Del Giudice, 2004).

Mean willingness to pay estimates can be calculated as follows

$$WTP_k = \left(\frac{2 * \beta_k}{\beta_1}\right), \quad (7)$$

where $\beta_k$ is the coefficient on the attribute and $\beta_1$ is the coefficient on increase in net revenue instead of price in a typical demand model. Instead of the usual {0,1} dummy variable, in effects coding the attributes takes on a value of 1 when applicable, a value of -1 when the base category applies, and zero otherwise (Tonsor, Olynk, and Wolf, 2009; Olynk, Tonsor and Wolf, 2010). The coefficient on attribute *k* is multiplied by two in equation (7) to calculate WTP for effects coded variables (Lusk, Roosen and Fox, 2003; Tonsor, Olynk, and Wolf, 2009), and the two is excluded when calculating WTP for the binary coded attribute conventional tillage.

There are numerous methods available to estimate confidence intervals for WTP estimates including delta, Fieller, Krinsky-Robb, and bootstrap methods. Hole (2007) found all of these methods to be reasonably accurate and yield similar results to one another; thus, the Krinsky-Robb method is used to construct 95% confidence intervals. One thousand observations for each WTP estimate were simulated by drawing from a multivariate normal distribution parameterized with the coefficients estimated using the RPL model and the variance-covariance matrix resulting from the same model (Krinsky and Robb, 1986).

In addition to mean estimates for the entire sample, the sample was divided into two groups based on revealed preference data indicating which respondents have already adopted either conservation tillage or no-till on their farmed acres and those farmers who have not adopted any form of reduced tillage. Split sample mean and individual WTP estimates were obtained for each attribute of the choice experiment. The complete combinatorial method proposed by Poe et al. (2005) was used to determine if there is a statistically significant difference between the WTP for different contract attributes, given respondents' revealed preferences for different tillage practices.

Recently, concerns in the choice literature have emerged around the potential use of decision heuristics on behalf of respondents in order to simplify choice tasks. Attribute Non-Attendance (ANA) refers to respondents ignoring attributes when choosing between alternatives (Scarpa et al. 2009; Hensher and Greene 2010). Ignoring attributes is especially concerning to researchers, marketers, and industry professionals, as failing to account for ANA *may* impact the marketing and policy conclusions drawn. Past research has found significant evidence of ANA with meaningful impacts on WTP estimates. Scarpa et al. (2009) identified over 90% of their survey population not attending to the price variable; this caused unrealistically high WTP estimates for rural landscape valuation. In this study we rely on an inferred method of ANA proposed by Hess and Hensher (2010) which uses the coefficient of variation (the ratio of standard deviation to the mean) on individual specific parameter estimates to measure the degree of noise-to-signal ratio on the variability of preference intensity for a given attribute as exhibited by the individual's choice behavior.

**Results**

The coefficients of the parameters estimated in the RPL model are displayed in Table 3. The percent of respondents exhibiting inferred ANA is also displayed in Table 3. Given the low levels of ANA found relative to the literature on its potential importance (Scarpa at al. 2009) and the insignificant differences in mean marginal WTP (MWTP) observed when attempting to correct for ANA, all results reported are from uncorrected models. Consistent with findings in Olynk and Ortega (2014), after correcting for inferred ANA the MWTP estimates did not exhibit differences that impacted the overarching conclusions.

All parameters were found to be statistically significant. Interpretation of individual coefficients is discouraged in random utility models, however, the coefficients had the expected signs and were used to estimate mean WTP and confidence intervals. Of particular interest is the positive sign of the monetary variable *Increase in Net Revenue*, which has the opposite expected sign of a cost parameter more commonly encountered in the consumer demand literature because it reflects revenue instead of cost. All of the parameters estimated as being random have statistically significant standard deviations (Table 3). Furthermore, all random parameters had statistically significant diagonal elements in the Cholesky matrix, indicating the presence of preference heterogeneity (Appendix C). Consequently, the mean marginal WTP (MWTP) estimates cannot be interpreted as being representative of the whole sample.

The mean MWTP estimates and the associated 95% confidence intervals are presented in Table 4. When interpreting these values, this number represents the value farmers place on this attribute when the effects coded or dummy variable equals one relative to the reference case (Table 2; Appendix A). Farmers' MWTP values for implementing conservation tillage or conventional tillage are \$3.21 and \$4.79, respectively, and are interpreted as the dollars per acre the farmer is willing to pay to implement these tillage practices relative to no-till. Not surprisingly, the negative MWTP for the contract attribute indicates that farmers would have to be paid $10.57 per acre to accept a multi-year contract that limits their ability to change tillage practices for the duration of the contract term. This result is distinct but nonetheless consistent with previous research that found Danish farmers value flexibility in contract terms of an agri-environmental policy to promote adoption of pesticide-free buffer zones (Christensen, et al., 2011). We refer to this as marginal willingness-to-accept (MWTA) payment for a contract attribute. The MWTA for carbon payments from either the government or a commodity market for carbon is relative to there being no carbon payment. Farmers would rather not be paid for carbon sequestration than receive payment from *either* source evaluated in the CE. This makes sense when you consider the full experimental design that includes alternatives with no explicit carbon payment from the government or a cap-and-trade market, but the possibility of an increase in net revenue from adopting either conservation tillage or no-till (Appendix B). This is consistent with farmers who have experienced a small or negligible reduction in yield after reducing or eliminating tillage while also saving on machinery, fuel and labor costs, thus increasing net revenue per acre relative to conventional tillage. Indeed, the vast majority of all farmers who have already adopted conservation tillage or no-till, as defined in our survey instrument, made the decision to reduce or eliminate tillage in the absence of any government or market payment.

**Discussion and Policy Implications**

The only two active carbon limits in the US today cover non-agricultural emissions in California and the nine northeastern states that are part of the Regional Greenhouse Gas Initiative

(RGGI). Recent secondary market spot prices in these two markets were $11.95USD and $4.74 USD per metric ton, respectively (CMNA 2014). Observed price differences reflect the relative scarcity of allowances and stringency of the carbon caps in each market, with prices in both individual markets reflecting the underlying abatement costs of firms (or the floor price, whichever is lower). While still in its infancy, the market for California Carbon Allowances (CCA) is the largest carbon market in North America in terms of volume, and carbon emissions regulations in California require more aggressive reductions over time than the RGGI market. Additionally, neither market has developed formal protocols for awarding certified emissions reductions (UNFCCC terminology), more commonly referred to as "offsets," for management of agricultural soils. Payments to farmers for offsets sold to participants in these markets are the basis for the cap-and-trade commodity market payment for soil carbon included in the experimental design.

The existing USDA Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) includes government conservation payments for implementing reduced tillage (practice code 345) and no-till/strip till (practice code 329) practices. These practices are the basis for the government payment source included in the CE (EQIP 2014). The 2013 EQIP payment levels in Indiana (for a maximum of two years) for conservation tillage and no-till/strip tillage are $4USD /acre and $14USD /acre, respectively (USDA-NRCS, 2014). Based on the 0.6 metric ton per acre per year carbon sequestration rate that was the basis for awarding offsets under the now-defunct Chicago Climate Exchange (CCX, 2009), these amounts are equivalent to $6.66USD and $25.33USD per metric ton sequestered. Table 5 takes farmers' revealed preferences for tillage practices into account to compare individuals' MWTP for different soil carbon sequestration contract attributes, and to determine the percentage of respondents with MWTP less than or equal to (i) the current EQIP payments for the same practices and (ii) carbon market prices. There is a statistically significant difference between the mean MWTP of reduced tillage adopters and non-adopters for the tillage type and multi-year contract attributes (Table 5 and Appendix D). The difference in MWTP for the payment source was not statistically significant for these two groups.

With an eye toward future policy development and more mature carbon markets that may include soil carbon offset protocols, it is important to examine individual decision makers' preferences for different attributes of any market-based payments or government contracts intended to compensate farmers for environmental services provided to society by agriculture. The results in Table 5 use respondent-specific random parameter estimates to calculate individual MWTP for each contract attribute included in the CE. The two rightmost columns of Table 5 report the equivalent EQIP payment rate and CCA carbon price per metric ton per acre of land per year, assuming the same carbon sequestration rate contained in the Chicago Climate Exchange offset protocols (CCX, 2009). These two payment mechanisms embody different levels of the attributes included in the CE, with EQIP having practice standards for conservation tillage and no-till, but the CCX offset protocols only allow contracts for no-till (or strip till) acres. Only 18% and 27% of respondents who did not report using any form of reduced tillage had MWTP less than the soil carbon equivalent EQIP payment rate for conservation tillage and no-till, respectively. Similarly, 16.5% of non-adopters had MWTP low enough to imply carbon offset market participation is possible (assuming no transaction costs). These percentages are particularly important from a climate change mitigation standpoint because only new or increased adoption of carbon sequestering practices results in additional emissions offsets relative to baseline practices when a new carbon market is created.

The UNFCCC has yet to approve protocols for soil carbon sequestration, despite a large body of research demonstrating that enhanced management of agricultural soils can achieve significant reductions in atmospheric carbon levels (McCarl and Schneider, 2001, Smith, et al., 2008) and prior development of protocols in two different carbon markets in North America. This research sheds light on the prices necessary to incentivize farmers to change tillage practices in order to supply carbon sequestration that offsets GHG emissions and the attributes of policies or market mechanisms that can be expected to be more or less attractive to the supply side of the soil carbon offset market.

**Contributions**

Gramig designed the study, supervised data collection, estimated statistical models and wrote the paper. Widmar oversaw model estimations, coded and performed the statistical comparisons via the Poe test and the attribute non-attendance tests, and wrote the paper.

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**Table 1.** Summary Statistics for Survey Respondent Demographic Information Compared to the State and Nation

| Characteristic | *n* | Sample % | NASS Indiana % | NASS US % |
|---|---|---|---|---|
| Age | | | | |
| 18-25 years (NASS: under 25) | 7 | 0.99 | 0.70 | 0.5 |
| 26-35 years (NASS: 25-34) | 25 | 3.52 | 6.80 | 4.8 |
| 36-45 years (NASS: 35-44) | 64 | 9.01 | 15.10 | 12.1 |
| 46-55 years (NASS: 45-54) | 174 | 24.51 | 27.60 | 25.6 |
| 56-65 years (NASS: 55-64) | 202 | 28.45 | 24.60 | 27.0 |
| 66-75 years (NASS: 65 and older) | 155 | 21.83 | 25.20 | 29.7 |
| 76 and older | 83 | 11.69 | | |
| Region (Indiana crop reporting district) | | | | |
| Northwest | 93 | 13.09 | 13.84 | |
| North Central | 82 | 11.54 | 12.31 | |
| Northeast | 93 | 13.09 | 10.92 | |
| West Central | 67 | 9.43 | 11.72 | |
| Central | 122 | 17.18 | 20.17 | |
| East Central | 58 | 8.17 | 8.86 | |
| Southwest | 97 | 13.66 | 13.50 | |
| South Central | 55 | 7.74 | 4.42 | |
| Southeast | 43 | 6.05 | 4.27 | |
| Off Farm Employment | | | | |
| 1-19 hours per week | 78 | 10.74 | | |
| 20-39 hours per week | 55 | 7.57 | | |
| 40 or more hours per week | 197 | 27.14 | | |
| No off-farm employment (NASS: Zero days worked off operation) | 396 | 54.54 | 33.2 | 35.2 |
| Education (NASS not available) | | | | |
| Did not complete high school | 27 | 3.67 | | |
| Completed high school | 270 | 36.78 | | |
| Some college, no degree | 132 | 17.98 | | |
| Associate's or Vocational degree | 83 | 11.31 | | |
| College Bachelor's degree | 133 | 18.12 | | |
| Some college graduate work | 18 | 2.45 | | |
| Completed graduate degree (M.S. or Ph.D) | 72 | 9.67 | | |
| Total Acres (Hectares) as of July 1, 2010 | | | | |
| 1-99 (1-40) | 177 | 24.96 | 62.7 | 54.4 |
| 100-499 (41-202) | 270 | 38.08 | 24.7 | 31.0 |
| 500-999 (203-404) | 102 | 14.38 | 6.2 | 6.8 |
| 1,000-1,999 (405-809) | 90 | 12.69 | 4.3 | 4.2 |
| Greater than 2,000 (greater than 810) | 70 | 9.87 | 2.1 | 3.6 |

Note: Number of observations used to estimate choice models may differ from totals due to unbalanced number of responses to each choice set by each respondent. Additional sample farm demographics are reported along with farmers' climate change beliefs in Gramig, Becker and Prokopy (2013).

**Table 2.** Attributes and Attribute Levels Evaluated in the Choice Experiment

| **Attribute** | **Attribute Levels** |
|---|---|
| Tillage Practice | Conservation tillage<br>No tillage (or no-till)*<br>Conventional tillage |
| Increase in Net Revenue | $10/acre<br>$5/acre<br>$0/acre* |
| Source of Carbon Payment | Commodity Market<br>Government Program<br>None* |
| Multi-year Contract Requirement | Contract Required<br>No Contract Required* |

Attribute and level definitions provided to respondents reported in Appendix A
* Denotes reference level for interpretation of econometric estimation results

**Table 3.** Estimated parameters (standard errors) from random parameters logit model

| Variable | Coefficient Estimates | Standard Deviation Estimates | Rate of Attribute Non-Attendance |
|---|---|---|---|
| *NetRev*: Net revenue | 0.16377*** (0.01022) | | 10% |
| *Tillage*: Conservation Tillage | 0.26093*** (.05064) | 1.05117*** (.08739) | 17% |
| *Conv*: Conventional Tillage | 0.77716*** (.18272) | 5.97281*** (.26280) | 4% |
| *Contract*: Contract | -0.86152*** (.05450) | 0.85563*** (.06391 | 7% |
| *Govt*: Government payment | -0.20278*** (.04824) | 0.68079*** (.07972 | 20% |
| *CAT*: Market payment | -1.04265*** (.06913) | 1.26141*** (.09214) | 16% |

Sample size n=648
*** denotes $p < 0.01$

**Table 4.** Mean marginal willingness to pay (MWTP) estimates and 95% confidence intervals

| Variable | Mean MWTP per acre | 95% Confidence interval [a] |
|---|---|---|
| Conservation Tillage | $3.21 | ($2.04, $4.63) |
| Conventional Tillage | $4.79 | ($2.70, $6.93) |
| Multi-year Contract | -$10.57 | (-$12.31,-$9.11) |
| Government payment | -$2.48 | (-$3.57, -$1.34) |
| Market payment | -$12.78 | (-$15.10, -$10.71) |

[a] 95% confidence intervals found using the Krinsky-Robb method (Krinsky and Robb, 1986).

**Table 5.** Mean marginal willingness-to-pay (MWTP) and percentage of respondents who have not adopted reduced tillage with individual MWTP less than equivalent conservation program payments or carbon offset market prices

| **Choice Experiment Attribute** | **Mean MWTP per acre, given have *not* previously adopted reduced tillage** | **Equivalent EQIP[a] Payment Rate** ***% Respondents with MWTP ≤ EQIP payment*** | **Equivalent CCA[a] Offset Price** ***% Respondents with MWTP ≤ CCA price*** |
|---|---|---|---|
| Conservation Tillage, relative to no-till | \$10.90*** | \$6.66/Metric ton/acre/yr[b] *18.4% ≤ EQIP payment* | Not Applicable[d] |
| Conventional Tillage, relative to no-till | \$40.38*** | \$25.33/Metric ton/acre/yr[c] *27.2% ≤ EQIP payment* | \$11.95/Metric ton/acre/yr *16.5% ≤ CCA price* |
| Multi-year Contract | -\$7.10*** | 2 years | Yes |
| Government Payment | -\$0.15 | Yes | No |
| Cap-and-Trade Market Payment | -\$15.38 | No | Yes |

*** $p<0.01$: Significance of difference in MWTP compared to respondents that have adopted reduced tillage (see Appendix D)

[a] Assumes 0.6 Mg per acre per year carbon sequestration rate based on Chicago Climate Exchange protocols (CCX, 2009); EQIP denotes USDA Environmental Quality Incentives Program and CCA denotes California Carbon Allowance

[b] Based on USDA-NRCS practice code 345 (EQIP, 2014) and Indiana 2013 payment rates (USDA-NRCS, 2014)

[c] Based on USDA-NRCS practice code 329 (EQIP, 2014) and Indiana 2013 payment rates (USDA-NRCS, 2014)

[d] Only tillage practices under NRCS practice code 329 (no-till and strip till) eligible under CCX offset protocols (CCX, 2009)

## APPENDIX A: CHOICE EXPERIMENT DEFINITIONS

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**Tillage practice**

**No-Till**: Greater than 30% of the soil remains covered in crop residue after planting. This category includes the technique more commonly known as strip-till, in addition to true no-till.
**Conservation Tillage:** 15-30% of the soil remains covered in crop residue after planting. This category includes techniques more commonly known as mulch-till & ridge-till.
**Conventional Tillage:** Any tillage system leaving less than 15% crop residue coverage after planting. This category includes the use of chisel and moldboard plows and typically involves multiple tillage trips per year.

**Increase in net revenue**

This describes the change in net revenue ($) per acre from adopting the tillage practice described above. It includes any fuel and labor savings, additional pesticide input costs, equipment overhead savings, and carbon payment received.
**$0/acre**
**$5/acre**
**$10/acre**

**Carbon payment**

**Commodity market**: Proposed legislated would create a commodity market for soil carbon payments to farmers would be based on the tillage practice they adopt.
**Government program**: Payments to farmers would be similar to existing conservation program payments from the government.
**None:** No carbon payment is made to the farmer under the stated tillage.

**Multi-year contract requirement**

**Contract required**: A multi-year contract is required for this alternative.
**No contract required**: No contract is required for this alternative.

**Note about Conventional Tillage option:**

Note that the characteristics of each no-till or conservation tillage option are expressed relative to the conventional tillage option. Under conventional tillage there is no market or government payment for carbon stored in agricultural soils, and there is no required contract.

## APPENDIX B: EXAMPLE CHOICE SET

**If these were your only tillage practice options, which one would you choose?**

| **Attribute** | **Option 1** | **Option 2** | **Option 3** |
|---|---|---|---|
| **Tillage Practice** | Conservation Tillage | No Tillage or no-till | Conventional Tillage |
| **Increase in net revenue** | $0/acre | $5/acre | |
| **Source of carbon payment** | Government | Cap-and-trade market | |
| **Multi-year contract requirement** | Contract required | No contract required | |
| **I Choose:** | ___ | ___ | ___ |

## APPENDIX C: CHOLESKY AND CORRELATION MATRICES

Cholesky Matrix

| | TILLAGE | CONV_D | CONTRACT | GOVT | CAT |
|---|---|---|---|---|---|
| TILLAGE | 1.0512[a] | | | | |
| CONV_D | -5.2334 [a] | 3.2997 [a] | | | |
| CONTRACT | 0.1584 [c] | 0.3247 | 0.7767 [a] | | |
| GOVT | -0.0328 | 2.0925 [a] | 0.0439 | 0.2900 [a] | |
| CAT | 0.2301 [b] | 2.3879 [a] | 0.4108 [a] | 0.4697 [a] | 0.4652 [a] |

Statistical significance: [a] = 0.01, [b] = 0.05, [c] = 0.1

Correlation Matrix

| | TILLAGE | CONV_D | CONTRACT | GOVT | CAT |
|---|---|---|---|---|---|
| TILLAGE | 1.0000 | -0.8335 | 0.1761 | -0.0458 | 0.1736 |
| CONV_D | -0.8335 | 1.0000 | 0.0635 | 0.5146 | 0.3169 |
| CONTRACT | 0.1761 | 0.0635 | 1.0000 | 0.0754 | 0.3806 |
| GOVT | -0.0458 | 0.5146 | 0.0754 | 1.0000 | 0.5469 |
| CAT | 0.1736 | 0.3169 | 0.3806 | 0.5469 | 1.0000 |

**APPENDIX D: Split sample estimation results used to conduct complete combinatorial test (Poe et al. 2005)**

Mean willingness to pay estimates, 95% confidence intervals and statistical test of difference between MWTP of each group

| Variable | Respondents who *have not* adopted any form of reduced tillage (n=103) | | Respondents who *have* adopted some form of reduced tillage on their farmed acres (n=545) | | P-Value Comparing WTP[b] |
|---|---|---|---|---|---|
| | Mean MWTP estimates | 95% confidence interval [a] | Mean MWTP estimates | 95% confidence interval [a] | |
| Conservation Tillage | $9.97 | ($6.02, $14.83) | $0.42 | (-$1.14, $2.00) | 0.0000 |
| Conventional Tillage | $33.97 | ($25.96, $45.07) | $1.11 | (-$1.11, $3.20) | 0.0000 |
| Contract | -$5.61 | (-$9.54, -$1.83) | -$10.48 | ($-12.36, -$9.33) | 0.0089 |
| Government | -$0.33 | (-$5.67,$5.71) | -$2.26 | (-$3.64, $0.97) | 0.2589 |
| Commodity | -$13.77 | (-$22.48, -$6.08) | -$10.89 | (-$13.11, -$8.84) | 0.7333 |

[a] Confidence intervals found using the Krinsky-Robb method (Krinsky and Robb, 1986).

[b] Complete combinatorial test (Poe et al. 2005) was performed; interpretation is such that a p-value of less than 0.05 would indicate statistical significance at the 5% level.

**APPENDIX E: COMPLETE EXPERIMENTAL DESIGN**

*Block 1*

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choice Set | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 |
| Alternative | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Attribute 1 - tillage | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| Attribute 2 - contract | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 1 |
| Attribute 3 – net revenue | 1 | 3 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 3 | 3 |
| Attribute 4 – C pymt | 3 | 2 | 1 | 2 | 2 | 3 | 1 | 2 | 3 | 2 | 1 | 1 | 3 | 3 | 2 | 1 | 3 | 3 |

*Block 2*

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choice Set | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 |
| Alternative | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Attribute 1 - tillage | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 2 |
| Attribute 2 - contract | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 2 |
| Attribute 3 - net_revenue | 3 | 3 | 2 | 2 | 3 | 2 | 2 | 1 | 3 | 2 | 2 | 3 | 1 | 1 | 1 | 3 | 2 | 2 |
| Attribute 4 - c_pymt | 1 | 2 | 2 | 3 | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 3 | 1 | 3 | 2 | 1 | 3 | 2 |

*Block 3*

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choice Set | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 |
| Alternative | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Attribute 1 - tillage | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 1 |
| Attribute 2 - contract | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 1 |
| Attribute 3 - net_revenue | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 1 | 1 | 3 | 1 | 3 | 2 | 1 | 2 | 3 | 2 |
| Attribute 4 - c_pymt | 3 | 3 | 1 | 3 | 3 | 1 | 2 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 3 | 3 | 2 | 1 |

*Block 4*

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choice Set | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 |
| Alternative | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Attribute 1 - tillage | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |
| Attribute 2 - contract | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 |
| Attribute 3 - net_revenue | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 3 | 2 | 1 | 3 | 1 | 3 | 3 |
| Attribute 4 - c_pymt | 3 | 1 | 1 | 3 | 3 | 3 | 1 | 1 | 3 | 2 | 2 | 3 | 2 | 3 | 3 | 1 | 2 | 2 |

*Notes*: Complete design size = 36; Each choice set (column above) included a conventional tillage option described in Appendix A; Tillage levels 1-2 = conservation tillage, no-till; Contract levels 1-2 = contract required, none; Net revenue levels 1-3 = $0, $5, $10; Carbon payment (c_pymt) sources 1-3 = government, market, none.