Why Do Farmers Adopt Soil Conservation Practices? A Theoretical Framework and Literature Review

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Introduction

As global populations continue to spiral upward, there is a great need for more productive agriculture to meet food and fiber needs. The main challenge of agriculture will thus be to sustainably produce enough food and fiber for the growing global population without sacrificing the environmental integrity and without unacceptable environmental costs (Robertson & Swinton, 2005). However, “under current management practices, soils across the globe are at risk of severe degradation” (Stevens, 2018). Anthropogenic activities such as intensive tillage of agricultural lands have worsened soil erosion and soil degradation. Some believe that at the current rate, “human security over the next century will be severely threatened by unsustainable soil management practices” (Amundson et al., 2015). One possible way to mitigate the problem of soil loss and degradation is through soil conservation practices.

One would expect that considering the potential benefits of soil conservation translates to an automatic adoption by all farmers. However, adoption of any new technology has challenges for the adoptee (Hall & Khan, 2003) especially when the new technology has uncertain returns and a fixed cost of adoption (Wozniak, 1987). Only when farmers are convinced that the benefits of conservation outweigh their costs will they be motivated to change their tillage methods and implement soil conservation techniques. It is not surprising that while some farmers have adopted conservation practices, others continue tilling their farms intensively. Furthermore, farmer decision making is not driven solely by economic incentives. Management “decision making is situated within diverse environmental, political, economic and cultural contexts that vary at different spatial scales” (Gray & Gibson, 2013; Harden et al., 2013; Stacey Swearingen White et al., 2009). Thus, conservation decisions should be considered “within the context of much broader structural imperatives and power dynamics that shape and influence the kind of relationships farmers and other producers seek to establish" (Lawrence et al., 2004).

In this paper we adopt a holistic model of farm management, taking into account a variety of factors that impact the farmers' soil management choices. In our model, we recognize that profit is but one factor that farmers look out for when deciding whether to adopt soil conservation techniques. We show that at least nine separate factors enter into farmers' conservation decisions, including scientific impacts of conservation and farmer perceptions. We then review the literature to establish what has been learned about each of these factors.

Our objectives are threefold: 1) to give a holistic concept of soil conservation and its importance, with particular attention given to conservation tillage 2) to develop and operationalize a dynamic optimization model, teasing it into various factors that determine why farmers choose to or not to adopt conservation tillage and 3) to review literature and determine what has been said about each of the factors derived in objective two affecting farmers decision to implement conservation tillage

Concept of Conservation Tillage

Broadly speaking, "conservation agriculture is defined as soil management practices that minimize the disruption of the soil's structure, composition and natural biodiversity and that include very little soil disturbance through tillage, permanent organic soil cover, and diversified crop rotations" (Ntshangase et al., 2018). Simply put, soil conservation is aimed at preserving the soil. One soil conservation method that merits in-depth study is conservation tillage. This is defined as planting of crops directly in the soil with little prior soil preparation; only a narrow strip is opened deep enough to deposit seeds and fertilizers (Bolliger et al., 2006; Christoffoleti et al., 2007). Conservation tillage, including no-till (NT), strip-till and other related practices, is gradually gaining popularity.

In NT conservation agriculture, planting takes place in an unprepared soil. It is a sequence of operations that reduce erosion caused by mechanically killing the vegetation on the field through the use of herbicides (Ntshangase et al., 2018). Moreover, farmers use a specific seeder machine, by creating a narrow furrow, just large enough for seeds to be injected, without turning the soil. Fertilizer is also injected with the seeds into the soil without the need to fertilize the whole field; then the furrows are closed up afterwards. With this method, the soil can be seeded and fertilized with minimal disturbance (Rouabhi et al., 2018) and more than thirty percent of the residue are retained on the soil surface for the entire season. These crop residues act as mulch and help protect soil surfaces and slows down run-off while increasing infiltration. Moreover, organic matter in crop residue traps moisture, reduce water evaporation and prevents soils from drying out.

In strip till conservation agriculture, minimum tillage is employed. This method disturbs only the portion of the soil that will contain the seed row thereby combining the soil-protecting advantages of no-till with the soil warming and drying benefits of conventional tillage. Strip till preserves residue cover between rows, conserves more soil moisture and reduces the number of trips made on a farm relative to intensive tillage thereby reducing soil compaction, reducing soil erosion, saving time and fuel. Moreover, strip till aerates the soil and creates a better seedbed than no-till.

Conventional tillage (CT) on the other involves multiple machinery passes in the field and buries most of the crop residue into the soil. Since this method plows under much of the crop stubble, it leaves the surface relatively exposed and vulnerable, devoid of crop residues and mulch.

Earlier studies have shown that using no-till provides a range of agronomic, environmental, ecological and social benefits (Islam & Reeder, 2014; Stavi et al., 2012). Lehman et al. (2015) studied the influence of tillage on the biological functions of soil and reached the conclusion that aggressive tillage disturbs the natural soil habitat, alter water and nutrient composition and distribution, affect soil structure negatively and disrupt filamentous organisms, all of which tend to reduce soil health. Studies have also shown that tillage-induced disturbance often has a negative impact on soil biota like earthworms and the services that they supply (Islam & Reeder, 2014; Kladivko, 2001; Köhl et al., 2014; Robertson & Swinton, 2005; Triplett & Dick, 2008). On the other hand, reduced tillage increases microbial biomass in the long term (Helgason et al., 2010; Lehman et al., 2015). In fact, combining conservation tillage with other beneficial farming practices such as "crop rotation or incorporation of perennial crops for integrated livestock and cropping systems increase arbuscular mycorrhiza fungi which enhance plant uptake of phosphorus and water, and disease resistance potential" (Davinic et al., 2013).

Despite these benefits however, trade-offs are unavoidable. While no-till soil management builds soil organic matter and adds trophic complexity to crop fields, it typically requires more chemical weed control (Chauhan et al., 2012) and there are other implications that might affect a farmer's willingness to adopt the practice of no-till.

Modeling the Farmer Decision Process

Researchers have presented models of why farmers might adopt soil conservation practices (Burt, 1981; Ciriacy-Wantrup, 1947). Burt (1981) specifically applied dynamic programming to study soil conservation in the Palouse area of Northwest United States but his decision variable was crop rotation (percentage of land allocated to wheat in the rotation). His result suggested that intensive wheat production with heavy fertilization was the most economic cropping system in that region, except when wheat prices were low. Likewise, McConnell (1983) introduced soil depth and soil loss into an optimal control model of agricultural production, but went further to study the difference between private and socially optimal solutions to soil erosion.

Pope et al. (1983) incorporated soil loss, topsoil depth, net farm income and technological progress into an optimal control model and found optimal values of soil loss and soil depth which maximize the stream of net farm income for planning horizons of varying length. Thereafter, Saliba (1985) studied relationships between farm management variables, soil loss, crop yield and incentives to practice soil conservation by farmers using optimal control model. In most of these studies, focus was on soil loss and soil depth as a measure of soil quality. Meanwhile, soil health is multidimensional since it takes into account physical, biological and chemical aspects.

More recently, Stevens (2018) also took a dynamic perspective in analyzing the soil conservation problem. He recognized the multidimensional aspect of soil health and presented an optimal control model that would allow the incorporation of multidimensional soil health characteristics, for both private and socially optimal management. From Steven's perspective, there are two broad approaches to understanding what drives farmers decision to adopt a sustainable management practice. The first is modelling based on "external conditions for agricultural production rather than individual producer attributes. In this view, behavior does not depend on specific farmer and individual perceptions" (Stevens, 2018). The second way is to examine farmer's stated reasons for choosing a management practice. While Stevens adopted the former approach in his paper, Saliba (1985) earlier related that "while erosion-productivity research is extremely relevant to economists investigating farmers' conservation incentives, it is not state-of-the-art models that influence actual conservation decisions. Farmers' perceptions of crop yield declines associated with soil loss on their land determine whether erosion control appears worthwhile to them." Our model attempts to unify these two approaches – modeling behavior from an economic perspective, while also incorporating farmer's perception into the model - in order to get a realistic, tenable answer to what drives producers to adopt soil conservation practices such as no till.

Risk also plays an important role. (Varner et al., 2011) relates that the decision to switch from conventional tillage to no-till depends not only on the potential to use saved labor productively elsewhere or to farm more land, but also on risk preferences of individual farmers. Segarra and Taylor (1987) did a regional study and applied dynamic optimization to soil conservation in Piedmont area of Virginia. While their model was flexible to allow incorporation of additional constraints, it did not consider the influence of risk on farmer decision making. In fact, most researchers who applied dynamic programming have assumed that farmers are risk neutral, whereas agriculture is fraught with risks and profits are not deterministic in given decision-state combinations (Krautkraemer et al., 1994). Our model explicitly includes risk aversion and the farmer's belief of whether adoption would affect the variance of profits – crucial aspects of farmers' everyday decision making process.

There is a dominant theme that runs through most dynamic optimization studies: maximizing net present value is assumed to be the sole aim of the farmer, without regard to other benefits the farmer may get from conserving the soil, such as social pressures to adopt or not adopt, or utility from a sense of stewardship or from high yields rather than profits.

Our model expands on the existing literature, taking into account not only the straight financial benefits and costs of NT, but the social, cultural, and local economic forces that enter into the farmer's choice. We propose a dynamic optimization model that and also review relevant literature on these determinants. We deliberately avoid the issue of externalities and social costs in this study because we seek a positive model of how farmers behave rather than the normative model of socially optimal soil management.

A Theoretical Framework for Soil Conservation Decisions

We adopt a dynamic model in which a farmer's objective is to maximize the present value of utility obtained from a given parcel of land. For simplicity we focus here on a binary choice variable, whether to adopt a soil conservation practice or not. While our model might be used for a range of soil conservation practices including crop rotation, cover crops and planted windbreaks, our focus will be on conservation tillage. The decision to adopt or not to adopt is captured by the binary variable z_C. Other annual choices, such as the application of fertilizer and herbicides, irrigation amounts, etc., are subsumed in a vector, $\mathbf{z}_t$, which we assume here are made optimally contingent on the soil conservation practice. The farmer's decisions and outcomes are also dependent on a vector of *state variables*, $\mathbf{x}_\mathbf{t}$ which are given at time *t* when the conservation tillage decision is made, but can be altered in the future. The vector of **"state variables**," $\mathbf{x}_t$ define the conditions that the farmer faces when making the decision about conservation in year *t*. This vector might include things easily measured like the farmer's bank balance or the equipment he owns. Importantly, the vector will also include conditions of the parcel being considered including *inherent soil conditions* that do not change from year to year and *manageable soil characteristics* that can change over time such as the soil's organic matter or level of compaction. For example, using conservation tillage can lead to increases in organic matter in the soil at time t+1 (Šimon et al., 2009). Finally, $\mathbf{x}_t$ could also include the farmer's human and social capital, including his knowledge of how to best use conservation practices and his ability to draw on insights from other farmers for advice.

Farmers' decisions, especially conservation tillage decisions, are dynamic in the sense that they take into account future outcomes as well as outcomes in the current-year. Assuming that the farmer seeks to maximize the present value of expected future utility, the farmer would make the soil conservation decision to solve the problem:

$$\max_{z_t^c} E_t u\left(\pi\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right), g_t, z_t^c, y_t\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right)\right) + \sum_{s=t+1}^{\infty} \beta^{s-t} P_s^L E_s u\left(\pi\left(z_s^c, \mathbf{x}_s, \varepsilon_s\right), g_s, z_s^c, y_s\right) \tag{1}$$

Where $u\left(\pi\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right), g_t, z_t^c, y_t\right)$ is single-period utility function which depends on the following: $\boldsymbol{\pi}$ represents profits[1] which is a function of conservation tillage decision z_t^C , vector of state variables (soil health characteristics) and vector of shocks beyond the farmer's control. g_t refers to government payments given as a reward to farmers who adopt conservation tillage. u is also a direct function of z_t^C which captures the non-profit benefits a farmer derives from doing conservation tillage perhaps due to having a stewardship ethic. In the same vein, u is a direct function of yield y_t if bragging rights are valued. The expression after the additive sign in equation one reflects the future benefits that accrue to the farmer due to his decision in time t. β is the discount factor which equals (1+*r*)$^{-1}$ where *r* is the discount rate, and P_t^L is the probability

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[1] For simplicity, we assume that other than the conservation tillage decision z_t^c, decisions affect profits in the current period but do not affect the vector of state variables. Hence, given that p is the vector of output prices and c is vector of input costs, profits in period *t* can be written as the solution to an optimization problem in period *t*, i.e.
$\pi\left(z_t^c, \mathbf{x}, \boldsymbol{\varepsilon}_t\right) = \max_{\mathbf{z}_t} E\left[p' y\left(\mathbf{z}_t, \boldsymbol{\varepsilon}_t \mid z_t^c, \mathbf{x}_t\right) - c\left(\mathbf{z}_t, \boldsymbol{\varepsilon}_t \mid z_t^c, \mathbf{x}_t\right)\right]$

that the farmer will be able to continue farming that parcel in each period.[2] The sum of maximized utility from period t to ∞ can be written concisely as the value function $V(\mathbf{x}_t)$, which captures the best expected utility that a farmer might be able to achieve starting in period t. Hence, **Error! Reference source not found.** can be rewritten as the Bellman's equation:

$$\begin{aligned} &V(\mathbf{x}_t) = \max_{z_t^c \in \{0,1\}} Eu\left(\pi\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right), g_t, z_t^c, y_t\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right)\right) + \beta P_L EV(\mathbf{x}_{t+1}) \\ &\text{s.t. } \mathbf{x}_{t+1} = \mathbf{f}\left(\mathbf{x}_t, \mathbf{z}, z_t^c, \boldsymbol{\varepsilon}_t\right), \end{aligned} \tag{2}$$

Operationalizing the Model

Equation **Error! Reference source not found.** provides a theoretical model for the soils conservation choice. To operationalize this problem and evaluate how different factors actually play on the decision about whether to adopt a soil conservation practice or not, let $\tilde{V}\left(\mathbf{x}_t, z_t^c\right)$ be defined as

$$\tilde{V}\left(\mathbf{x}_t, z_t^c\right) = Eu\left(\pi\left(y_t, z_t^c, \mathbf{x}_t, \varepsilon_t\right), g_t, z_t^c\right) + \beta P_L EV(\mathbf{x}_{t+1})$$

If $z_t^c = 1$ implies adoption and $z_t^c = 0$ implies non-adoption, then a farmer will adopt soil conservation if $\tilde{V}(\mathbf{x}_t, 1) - \tilde{V}(\mathbf{x}_t, 0) = \Delta\tilde{V} > 0$.

Applying Taylor series expansion[3] to our model, we can write out the complete approximation of the value to the farmer of adopting the conservation practice:

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[2] No one actually lives forever, but we use an infinite-horizon framework as an approximation of the intergenerational optimization problem that a farmer might solve.

[3] A detailed breakdown of this procedure is found in the Appendix

$$
\begin{aligned}
&\tilde{V}\left(\mathbf{x}_t, z_t^c = 1\right) - \tilde{V}\left(\mathbf{x}_t, z_t^c = 0\right) \approx \\
&\qquad + E\left[\begin{array}{r} u_\pi \cdot \left(\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right) + u_g \cdot \left(g\left(1\right) - g\left(0\right)\right) + u_z \cdot \left(1 - 0\right) \\ + u_y \cdot \left(y\left(1, \mathbf{x}_t, 0\right) - y\left(0, \mathbf{x}_t, 0\right)\right) \end{array}\right] \\
&\qquad + \beta\left[\frac{\partial P_L\left(\cdot\right)}{\partial z}\left(1 - 0\right) \cdot EV\left(\mathbf{x}_{t+1}\left(0\right)\right) + P_L E \frac{\Delta V\left(\mathbf{x}_{t+1}\right)}{\Delta \mathbf{x}_{t+1}}\left(\mathbf{x}_{t+1}\left(1\right) - \mathbf{x}_{t+1}\left(0\right)\right)\right] \\
&\qquad + \frac{1}{2} u_{\pi\pi} \cdot \left[\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right]^2 \\
&\qquad + \frac{1}{2} u_{\pi\pi} \cdot \left[Var\left(\pi \mid z_t^c = 1, \mathbf{x}_t\right) - Var\left(\pi \mid z_t^c = 0, \mathbf{x}_t\right)\right].
\end{aligned}
\tag{3}
$$

A farmer will adopt the conservation practice if **Error! Reference source not found.** is greater than zero. The adoption decision, therefore, depends on at least seven factors:

1. The farmer’s expectation of the change in utility from mean profits:

   $$u_\pi \cdot \left(\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right) + \frac{1}{2} u_{\pi\pi} \cdot \left[\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right]^2$$

2. The extent to which the farmer gains non-monetary benefits (e.g. bragging rights) from yield:

   $$u_y \cdot \left(y\left(1, \mathbf{x}_t, 0\right) - y\left(0, \mathbf{x}_t, 0\right)\right)$$

3. The financial and non-financial impacts of government payments on utility:

   $$u_g \cdot \left(g\left(1\right) - g\left(0\right)\right)$$

4. The farmer’s utility derived from a sense of soil stewardship and social interactions u_z

5. The probability of securing lease P_L and the extent to which the adoption decision affects the farmer’s future access to the field $\frac{\partial P_L}{\partial z^c}$

6. The extent to which the farmer Values Changes in Future Soil Health Characteristics

   $$\frac{\Delta V}{\Delta x_{t+1}^j}(\mathbf{x}_{t+1}(1) - \mathbf{x}_{t+1}(0))$$

7. Farmer's risk aversion and effect of adoption on variance in profits

$$u_{\pi\pi} \cdot \left[Var\left(\pi \mid z_t^c = 1, \mathbf{x}_t\right) - Var\left(\pi \mid z_t^c = 0, \mathbf{x}_t\right) \right]$$

Other elements of the vector of state variables are not as easily captured, but can also be very important. In particular, the farmer's may believe that they have the ability to learn quickly, so that while they may make mistakes in early years of adoption, their human capital may grow quickly, increasing the ability to generate higher profits and utility in the future.

As we will explore in this paper, there has been substantial research on many of these factors that influence the decision to adopt soil conservation. There has never, however, been attempt to pull together the range of studies that explore the multiple factors that influence farmers' conservation choices. In this paper we will provide a systematic answer to the question, what do we know about why farmers adopt soil conservation practices?

1. The farmer's expectation of the change in mean profits due to adoption

The role of the change in profits in equation **Error! Reference source not found.** by $u_\pi \cdot \left(\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right) + \frac{1}{2} u_{\pi\pi} \cdot \left[\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right]^2$. The core of this expression is the change in profits, $\left(\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right)$, how adopting conservation tillage affects the farmer's profits in the current year. The expression takes into account both the direct effect on utility, u_π, and the curvature in the utility function $u_{\pi\pi}$.

Profit motive is a crucial determinant and a "gatekeeper factor in making decisions about soil management" (Bagnall et al., 2020). Ryan, Erickson, and De Young (2003) found that a driving force for adoption of no-till was because adopters believed reducing soil erosion makes economic sense. Very few farmers will willingly adopt conservation practices if that leads to substantial reduction in income. Profit π in itself is a function of selling prices, yield and cost of production: $\pi\left(z_t^c, \mathbf{x}, \boldsymbol{\varepsilon}_t\right) = p.y\left(\mathbf{z}^*, \boldsymbol{\varepsilon}_t \mid z_t^c, \mathbf{x}_t\right) - c\left(\mathbf{z}^*, \boldsymbol{\varepsilon}_t \mid z_t^c, \mathbf{x}_t\right)$

The yield in this function is disaggregated from the one that gives non-pecuniary benefits but is considered here as a factor that affects farm level profits. Undoubtedly, profits are a primary motivating factor for farmers' decision making process. Blesh and Wolf (2014) for example, showed that conventional soybean and corn farmers are mainly "operating within a productivist system that is oriented toward maximizing yield and profit" in the Corn Belt. Previous research has shown that farmers hold the general opinion that their soils should be used to maximize their income and that profitability is an impetus for management decisions (Bennett & Cattle, 2013; Bennett et al., 1999; Guerin, 1999), most likely due to the industrialization of agriculture (Keller & Brummer, 2002). Indeed, studies show that the effect of adopting soil conservation techniques on farm profits has had varied outcomes. Certainly, fuel and labor costs associated with tillage decline if it is kept to a minimum. Cole & Johnson (2002) found that "adoption of conservation practices were economically sound because reduced tillage decreased production costs and brought economic payoff in the short run." In a study carried out in Brazil, Fuentes-Llanillo et al. (2021) analyzed the gross margins per hectare per year over six years for six different tillage systems and found that a no-till system were most profitable. This result corroborates previous works which indicates that crop rotation is one of the most efficient practices especially when combined with no till (Lehman et al., 2015). Archer et al. (2008) also compared irrigated corn under conventional-till and no-till in northern Colorado over six years. While grain yield was lower for NT relative to TL, lower machinery and operating cost seemed to compensate for it. They found that NT irrigated continuous corn is an economically viable option for replacing TL production systems, especially when combined with the environmental benefits of the NT system.

One factor that has a direct effect on yield and cost of production, and hence on net profit is the size of farm holdings. In our framework the benefits of cultivating larger parcels of land are subsumed in the utility function in our mathematical model. Yet, it would be remiss not to mention this since previous literature has consistently mentioned it as a key factor that determines whether farmers adopt no-till and other soil conservation practices. Farm size has consistently been found as a key factor that increases adoption of conservation tillage (Baradi, 2005; Fuglie, 1999; Gould et al., 1989; Ryan et al., 2003; Upadhyay et al., 2003; Vitale et al., 2011). “Researchers hypothesized that this was due to these farms’ ability to spread initial investments over greater acreage and utilize higher revenues as a cushion against the risk of potential losses” (Carlisle, 2016). Decker et al. (2009) further showed that farm size matters with regards to yield and profit in wheat production, and the economic incentives are less for smaller farms. Hösl and Strauss (2016) discussed problems when applying conservation tillage on small scale farming systems. Usually the change in farming system and the associated cost of such a change may result in socio-economic problems for many small-scale farmers. Shively (2001) carried out simulations based on a stochastic dynamic model and showed that probability of adoption of soil conservation in the Philippines increased with farm size. This is because it is especially costly for small farms to invest in soil conservation techniques because it increases the short run risk of consumption shortfall with certainty. For this reason, marginally food-sufficient households avoid soil conservation because adoption pushes them into regions of insufficiency.

So far, we have seen from past studies that the decision to adopt conservation tillage affects cost of production and crop yield which directly affects profit. In turn, profit is a crucial determinant of farmer’s utility. It is therefore important to include these pieces into the dynamic optimization model in order to reach a robust conclusion of farmers’ adoption behavior.

Previous research using focus group discussions with farmers have shown that profitability is a major theme relevant to farmer’s decision making. For example, the focus groups conducted by Arbuckle and Roesch-McNally (2015) and Basche and Roesch-McNally (2017) for farmers in Iowa and that of Bagnall et al. (2020) for farmers in Texas, all point to the same conclusion: that is economic returns were emphasized as key for adoption and soil health is good for farmers’ profits. Baradi (2005) reached the conclusion that adopters of soil conservation practices in Kansas perceived that no-till agriculture is more profitable. Earlier, Saliba (1985) opined that farmers consider both erosion vulnerability of their land and expected crop yield declines when they make conservation decisions and this is because these attributes have a direct impact on profit.

However, some farmers may not consider adoption of no-till as profitable due to equipment and cost considerations needed for a change of practice. Research has identified opportunity costs, initial investment in equipment and running cost in seed, labor and management to be factors that affect the final profit, which in turn has a direct impact on whether farmers choose to apply soil conservation. Farm technologies for example tend to be adopted more readily when farmers can quickly and easily test them on part of their land and farmers can achieve this if the initial purchase cost of equipment is low. But if farmers lack access to the specialized equipment they would need because of high cost of purchase, this could discourage them from performing low-investment experiments with the practice. It is only when farmers are convinced of the benefits and resiliency of the technology would they be decisive in investing a huge amount of money into equipment hopefully to be used for many years to come. Apart from fixed costs incurred in equipment required to do conservation tillage, running costs—in seed, labor, and management has also been found by several studies to be important barriers to adoption of new technologies (Bergtold et al., 2012; CTIC, 2014;Mallory et al., 1998). If a change to conservation tillage is construed to involve some costs and farmers perceive that their overall cost of production is already too high due to increase in variable costs, farmers may choose to remain with the status quo and not distort their already ‘stable’ farming regime. Costs incurred in order to apply soil conservation techniques like no-till could certainly be a hindrance to their adoption.

2. The extent to which the farmer values non-monetary benefits from yield increase:

We capture this effect by $u_y \cdot \left(y\left(1, \mathbf{x}_t, 0\right) - y\left(0, \mathbf{x}_t, 0\right) \right)$ in equation **Error! Reference source not found.**. Hence it is composed of two parts, the extent to which yields have a direct effect on utility, u_y, and the extent to which yield is affected by adoption of the conservation practice, $\left(y\left(1, \mathbf{x}_t, 0\right) - y\left(0, \mathbf{x}_t, 0\right) \right)$, which could be positive or negative. Since production inputs are generally not free, yield maximization is not necessarily synonymous with profit maximization. Yet, there is this innate satisfaction that farmers get from bumper harvest that is not pecuniary in nature, perhaps larger than what is needed for profit maximization. From bragging rights at the coffee shop to county prizes for the most bushels per acre, there are often non-monetary benefits from yield that are over and above the impact of yield on profit. In fact, many farmers connect productivity goals with the idea of being a ‘good farmer’ (Kumar, 2016). Related to this point but also critical is that since crop insurance payments are calibrated based on historical yields (Vera et. al. 2017), farmers could have a perverse incentive to keep yields high even at the expense of profits so that they can get more insurance benefits. Moreover, fear of low yields have been found to discourage farmers from adoption of new technologies. (Chi & Yamada, 2002)

The goal of being a “very productive” farmer can influence farmer’s decision to adopt a certain practice. Farmers who put a great deal of weight on yield would thus adopt no-till only if they believe that this practice will increase their yields. Behavioral focus on productivity has been explained through the agricultural production paradigm (Keller & Brummer, 2002) which has resulted in production-based economic farming models that influence some landholders to focus mainly on increasing production.

While it is established that farmers like high yield, it is necessary to know whether no-till farming actually increases yield. Previous tillage studies have reported inconsistent results for yield differences between NT and CT systems (Anderson, 2016; Bordovsky et al., 1994; Clark et al., 1996; Jones & Popham, 1997). Some studies have found greater yields with NT, others have found lower yields and still others have found no difference (Varner et al., 2011). Meta-analysis of experimental studies have being carried out in this regard. For example, (Morugán-Coronado et al., 2020) showed that in Mediterranean conditions, conservation tillage had no significant effect on yield compared to conventional tillage but overall it contributed to improvements in soil quality and fertility. (Pittelkow et al., 2015) did a global meta-analysis for various crops and found that no-till matched conventional tillage for oilseed, cotton and legume crop categories, but only began to match conventional tillage in other crops after three to 10 years depending on the crop category, with no till yields never exceeding those of conventional tillage. In contrast to these studies, (Afshar et al., 2019) found that no-till produced similar yield and quality of sugar beet relative to conventional tillage. These varying results are not surprising because yield differences between NT and tilled plots depend on a variety of factors such as number of years of practice of NT, type of crop grown, type of soil, climate of the farming region, technology employed, among others (Toliver et al., 2012). No-till technique therefore, deserves to be studied better in the agro-climatic context before deciding on their adoption by professionals. (Zaghouane et al., 2006).

Deines et al. (2019) acknowledged that yield impact is a key factor for farmer adoption. Using satellite technology and causal forest - a novel machine learning approach developed to detect causal inferences of observational data – to study effect of tillage on maize and soybeans yield in the US Corn Belt from 2005 to 2017, they found small yield increase from conservational tillage across tens of thousands of fields. For example, across fields with long tillage practices from 2008 to 2017, they found an overall 3.3% yield benefit from conservation tillage which translates to about 0.36 t/ha and about 0.74% yield benefit for soybeans or 0.024t/ha showing that soil conservation had minimal and positive yield impacts. They further found that initial implementation of conservation tillage did not bring instant benefits in terms of high yield but accrued over time as soil health and management improved. When considering fields between 1 and 8 years of adoption, it was estimated that for each additional year under conservation tillage, maize and soybeans found an overall positive effect of 0.29% and 0.033% respectively. In fact, their study showed that full yield benefit of long term conservation is achieved after 11 years for maize and 22 years for soybeans which suggest that soil benefits are greatest under sustained conservation tillage.

In a study carried out at the Southwest Oklahoma Agricultural Statistics District, Varner et al. (2011) did an economic comparison of NT and CT for dryland cotton, grain sorghum and wheat for a six-year period. Their study showed that mean wheat and cotton yields were not different between tillage systems over the six-year period. Results of later work showed that when soil conservation techniques are carried out on a farm, soil health improves quickly, while crop yield improvements may take longer (Islam & Reeder, 2014).

There is overwhelming evidence that no-till yields do not do better than conventional tillage yields for most crops which might be a disincentive for some not to adopt soil conservation especially for farmers who are yield oriented. However yield results are location and crop specific and such context must be taken into account.

3. Utility derived from government payments for adopting soil conservation practices

The utility derived from government payments for adopting no till is captured by $u_g \cdot \left(g(1) - g(0) \right)$ in equation (3).[4] Agri-environmental programs reward producers for environmental stewardship. A core component of environmentalization is increased government involvement in agricultural production, often through voluntary agri-environmental agreements in which producers willingly enroll in government schemes that provide financial incentives to adopt specific production practices (Evans et al., 2002; Wilson & Hart, 2001). The major federal cost-share program in the United States that pays for environmental services including no-till is Environmental Quality Incentives Program (EQIP).

In a comparative study of agronomic and economic feasibility of annual cropping no-till systems with traditional tillage-based winter wheat experiments in Eastern Washington, analysis showed that including government subsidies did not alter the profitability ranking of both cropping systems (Nail et al., 2007). Carlisle (2016) argued that “while cost share appears to have been important in the relatively widespread adoption of conservation tillage, impacts of the payments themselves are difficult to tease out from the technical assistance and education campaigns that have accompanied them, as well as farmers’ intrinsic and agronomic motivations to reduce erosion” (Carlisle, 2016). Other studies have shown that cost share was more important to

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[4] Such payments can be contingent on farm activities (e.g. CRP payments), and may be subject to some uncertainty even if the application has been submitted (e.g. EQIP).

interested non-adopters than early adopters (CTIC 2015), and more generally, that its role may be to financially assist farmers whose primary motivations are noneconomic (Arbuckle, 2013).

A pertinent question to ask is whether such government payments really motivate farmers to adopt no-till. One would typically assume that g_t would simply be valued based on its net monetary value, but government payments might also enter non-linearly into the utility function, such as if accepting money from the government carries a negative stigma. Hence, a farmer's valuation of government payments would depend on a number of factors such as the extent to which farmers can get payments for adopting conservation tillage, farmers' perception towards government payments and stewardship and the farmers innate risk behavior. In a study of farmers in England, Posthumus & Morris (2010) argued that UK farmers were driven by financial incentives (including agri-environment payments). If that is true, then the farmer looks at government payment the same way he views profit, then u_g=1. However, if there is some reluctance from participating in these programs perhaps due to some social stigma associated with accepting money from the government, then u_g<1 and if the farmer views government payment as a badge of honor, then u_g>1. Few studies have actually focused on the effect of government payments on farmer behavior. Mezzatesta, Newburn, and Woodward (2013) concluded that enrollment in federal cost-share programs in Ohio achieved positive and significant levels of additionality[5] for no-till, but that farmers who did not receive government support were almost as likely to adopt no-till as those who did receive funding.

Reasons they reported for reluctance to participate in these programs included high transaction costs, eligibility restrictions, requirements of some engineering specifications requirements of

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[5] Additionality refers to "whether the environmental service that are supported under a given program would have been provided in the absence of the payment" (Horowitz and Just, 2013)

long-term commitments and negative attitudes toward the government (Mezzatesta et al., 2013). Dobbs & Pretty (2008) further showed that incentivization of farmers through government "payments were sufficient to enroll farmers in simple programs but did not succeed to convince farmers to enroll in conservation programs that required more substantial changes in farming practices."

The differences in outcomes of various studies on this matter may be "attributed partly to differences in cultural context, but also to differences in methodologies used as each method focused on particular factors that influence adoption decisions" (Prager & Posthumus, 2011). This is in line with Knowler and Bradshaw (2007) who showed that various analytical procedures adopted by different researches "influences the results of the analysis, thus ultimately shaping our understanding of the world. They further argued that some causal variables in adoption decisions may simply reflect the influence of the region within which an analysis is undertaken which points to a need to undertake comparative studies across different contexts." In fact, a single model may be incapable of addressing the heterogeneity of farms, farmers and farm communities (Carlisle, 2016).

Overall, evidence suggests that government payments alone are not sufficient to motivate farmers to do conservation tillage due to varying preferences of farmers towards such payments and due to problems such as additionality. Thus such government efforts should be part of a more rounded, robust and diverse policies geared towards encouraging farmers to engage in sustainable practices.

4. Soil stewardship, environmentalism and social Interactions

The next factor captured by u_z in equation (3) considers the direct non-market benefits (positive or negative) arising from a sense of environmental stewardship that might be derived from adopting conservation tillage. The decision to adopt the conservation practice can affect a farmer's utility beyond the impact that it has on yields, costs, or soil health. For example, Farmers may derive utility from a sense of stewardship and environmentalism as caretakers of the land for the future generation. Some farmers may express reluctance to adopt no-till because it diminishes the aesthetic beauty of the farm while others may value the adoption because it demonstrates to neighbors the farmer's concern for the environment and makes them appear to be good farmers in the community. Also, if their peers adopt no-till, there may be satisfaction from a sense of belonging if they adopt as well. Evidently, "agriculture is a social endeavor shaped by market forces, social and economic policy and human values. Thus, the adequacy and environmental impact of agriculture depends on how effectively stakeholders understand and manage both the social and ecological elements of agricultural ecosystems" (Tilman et al., 2002).

Soil stewardship is the recognition of our individual and collective responsibility to manage the soil in a way to conserve all its biophysical and biochemical values with the goal of improving soil health so that future generation can benefit therefrom. Not only future generations may reap the rewards of stewardship ethic however. Producers may recognize that it is in their own economic and ecological interests to harvest the productivity profits and foster a stewardship ethic by managing their farms to increase soil organic carbon. In human and natural systems, "people and nature interact reciprocally and form complex feedback loops" (Liu et al., 2007). Such feedbacks could motivate a farmer to action to take care of his soil. For example, farmers who observe visible problems like gully erosion in the farm might be moved to use conservation tillage system to mitigate the problem (ROMIG et al., 1995).

Thus, farmers with a strong stewardship ethic may more readily adopt conservation agriculture and reorient their farm production practices, which would have soil building and soil saving at their center (Cruse et al. 2013; Roesch-McNally, Arbuckle, and Tyndall 2018) without necessarily depending on any sort of incentivization from the government, since soil conservation would simply be the right thing to do from their perspective.

In regard to non-market benefits, Ryan et al. (2003) found that a key factor in adopting no-till was the desire to conserve land for future generation. Stewardship ethic has been an important factor that facilitate the adoption of soil health promoting practices over the past three decades (Prokopy et al., 2019). Other studies have employed focus group discussions and soil stewardship ethic was a common theme that arose as a determinant of adoption of soil conservation practices (Bagnall et al., 2020; Roesch-McNally et al., 2018).

Apart from a stewardship ethic, farmers are influenced by their interactions with other people. Landlords, family, neighboring farmers, non-farming neighbors and people near farmer’s operations all have opinions on how farmers manage their land (Bagnall et al., 2020). Surely, beyond farmer’s immediate social networks, the communities in which they live exercise a great deal of influence on the choices they make (Bennett et al., 1999; Carolan, 2005; Welsh, 2006). Farmers are influenced by what they think people think of them. Thus they may want to hold a reputation of “being a good farmer”. To this end, Ryan et al. (2003) indicated that “concern for neighbors” and “farmer’s belief that soil conservation makes the farm appear well managed” were both important factors that increased adoption of soil conservation practices in Michigan.

This is not unexpected; neighbors or people whom the farmers have a relationship with typically evaluate one another's farm visually. Thus farmers are more likely to adopt soil health practices which convey the message that they are good stewards of their land. Social pressure however does not consistently favor conservation tillage. In focus groups, Bagnall et al. (2020) found that some farmers feel pressure to not adopt NT because the residue that remains on the land suggests to some neighbors poor farm management.

Whether NT is viewed favorably by a farmer can also be correlated with the farmer's social connections; farmers who are connected to others who are using soil health practices were more likely to adopt them (Carlisle, 2016). One study showed that the presence of early adopters who are willing to share their experiences with others in a given region increased other farmers' access to knowledge and infrastructure required to engage in the soil health practice (NWF 2012).

The bottom line is that soil stewardship and social pressure are critical factors in soil conservation tillage decisions. Evidence has shown that a key factor in adopting no-till is the desire to preserve land for the future generation; that farmers have stewardship ethic as a major theme and that adoption increases with an increase in social connections especially with contemporaries who are also adopters. These evidence therefore suggests that proper education and robust training should be skillfully targeted toward individual farmers and farmer groups in regard to the current and future benefits of conservation tillage in order to build stewardship ethic in farmers who are generally affected by the social groups they belong to.

5. Probability of securing lease and the extent to which the adoption decision affects the farmer's future access to the field.

It has long been known that land tenure has important implications in the decision making process – farmers with little confidence that they will be able to continue to work a particular parcel, i.e. P_L is small, have little incentive to invest in soil health. In equation 3, we also emphasize that the adoption decision can be affected by $\frac{\partial P_L}{\partial z^c}$, i.e. how adoption itself affects the probability of being able to renew a lease.

An integral part of US production agriculture is the leasing of agricultural land (Cole & Johnson, 2002). In 2016 report by USDA's Economic Research Service, approximately 39 percent of the 911 million acres of farmland in the contiguous 48 states was rented in 2016, raising the question: how will a farmer's desire to adopt soil conservation practices be impacted when he does not own the land, and especially if he suspects that he will be less likely to farm on the parcel in the offing? Since we assume expected utility is additively separable over time, future benefits of adopting no-till on a parcel would be zero if probability of retaining lease of that land is zero. This issue is worth considering because of population pressure and urban growth which has reduced number of parcels for sale and has raised prices of land; these factors seem to be inversely correlated with probability of retaining leased land next farming season. In Texas for example, population has increased by 21% since 2010. This percentage increase is expected to be 88.3% by 2050 indicating this stress on farmland is likely to worsen (Texas Demographic Center, 2021).

Standard theory suggest that in contrast to landowners who may have strong incentives to invest in soil conservation to protect the value of their land, renters may focus on short-term profits and, in doing so, deplete the soil due to their shorter planning horizon. Several empirical works have been carried out on land lease and land tenure effects on adoption of soil conservation practices. These results show that land tenure is an important factor in farmers' decisions to adopt conservation practices. Fraser (2004) argued that "farmers who engage in long-term soil conservation may sacrifice immediate income for the promise of better soil fertility and enhanced production in the future; since there are no guarantees that farmers who rent land will reap the benefits of long-term soil conservation, tenant farmers are expected to use management strategies that maximize short-term production even if this compromises future soil fertility." In his work, he added that "even long term lease did not seem to provide the same incentives as land ownership". Soule et al. (2000) admitted that "different lease arrangements may also influence renters' conservation decisions. For example, share-renters may have an additional incentive, relative to cash-renters, to adopt conservation practices that increase use of inputs for which they bear only a share of the cost. Furthermore, landlords tend to participate more actively in the management of farms rented under share leases. This could induce share-renters to behave more like owner-operators than cash-renters." For example, in analyzing the effect of land tenure on soil conservation adoption using logistic regression, Soule et al. (2000) found that "cash-renters were less likely than owner-operators to use conservation tillage, while share-renters behaved much like owner-operators in adopting conservation tillage."

Other studies have likewise supported conventional expectations that owner-operators are more likely to adopt conservation tillage than renters. (Belknap & Saupe, 1988; Lynne et al., 1988; Ribaudo & Shoemaker, 1995). Moreover, Abdulai et al. (2011), Gebremedhin and Swinton (2003) and Lovo (2016) empirically showed that tenure security had a positive effect on soil conservation investments in different African countries. Muraoka et al. (2018) argued that this is primarily true for long-term investments and productivity involving horizons of longer payoff, but not for investments that pay off in the same year. Tenure security can also influence access to credit, the length of a household's planning horizon or a household's willingness to invest (Shively, 2001).

Other studies have found no significant relationship between land tenure and investments on adoption of conservation tillage. (Lee and Stewart 1983; Gustafson and Bills (1984); Rahm and Huffman (1984); Brasselle et al. (2002); Cole and Johnson 2002). Lee and Stewart (1983) for example argues that while a longer planning horizon "tend to encourage conservation decisions by increasing the present value of expected net revenues and by allowing sufficient time to recoup conservation investments", such argument does not apply in the case of minimum tillage for two reasons. First, there are immediate economic advantages realizable by the farm operator in terms of energy, labor and soil conservation and second, investments in minimum tillage are closely associated with the farmer, not the landowner unlike other soil conservation techniques like terracing and gully control that permanently alter the land.

In regard to $\frac{\partial P_L}{\partial z^c}$, divergence or convergence of soil management preferences of both the landowner and the farmer may affect the sign and magnitude of the change in probability of securing lease due to adoption of the conservation practice. Pressure from landowners may have some significant impact on decisions of the farmer. For example, landowners who want a 'neat and tidy' piece of farmland may not support no-till since conventional tillage creates a more aesthetic appealing landscape. On the other hand, landowners who are well informed of the value of no-till for soil health may prefer that their tenants adopt no-till farming.

A number of studies have considered the effect of adoption decisions on probability of securing land the next farming season. Brasselle et al. (2002) for example, empirically showed that land tenure can be affected by adoption decisions such as investments in soil conservation practices. Deininger and Jin, (2006) similarly showed that “there was evidence suggesting that the causality may run the other way, i.e. that investment may be undertaken to enhance tenure security rather than as a response to higher levels of tenure security.” In a more recent study, it was shown that farmers in an Ethiopian community are “making substantial investments to halt and reverse land degradation – though to quite differing degrees – and by so doing, are simultaneously investing in the security of their land tenure” (Moreda, 2018).

The general evidence demonstrates that probability of securing lease and the effect adoption has on future leases weigh on the farmere mind in deciding whether to make a switch from CT to NT. In order to reconcile divergence in preferences of both landlord and farming operator if any, it has been suggested that cooperative practices such as share-leasing be embarked on whereby the landlord will contribute part of the costs of production e.g. fertilizer and herbicide costs (Lee and Stewart 1983). Landowners have an incentive to be more actively involved in conservation decisions under share agreements than under cash leases and may become more interested in improving soil health characteristics with long term yield improvement in sight rather than focusing on irrelevant objectives such as farm aesthetics. Thus the goal of a farmer would become the goal of the landowner, which in turn could boost probability of adoption of conservation decisions by the farmer, with the knowledge that adopting would not lead to loss of lease but enhancement of it in the future

6. The extent to which the farmer values changes in future soil health characteristics

When farmers make decisions in the current period, they do not think about the present benefits alone. The future benefits of doing no till would depend on farmer's perception of how changes in soil health characteristics would affect his total future utility. These are represented by $EV(X_{t+1}(0))$ which reflects farmer's perception of what his future expectations would be without doing conservation tillage and $\frac{\Delta V}{\Delta x_{t+1}^{j}}(\mathbf{x}_{t+1}(1)-\mathbf{x}_{t+1}(0))$ which reflects the additional value created from doing it. Of particular interest is $\frac{\Delta V}{\Delta x_{t+1}^{j}}$, to what extent to farmers value changes in soil health characteristics. Put succinctly, a farmer would gain more utility from doing conservation tillage if he places much value on improvement in soil health characteristics. Ervin and Ervin (1982) for example found perception of erosion problem by farmers an important determinant of adoption of minimum tillage. That means such farmers believed that minimum tillage would improve soil health and reduce erosion problems. Walker and Young (1986) also found that farmer's expectations concerning progress in technologies that improve yield can motivate adoption of conservation tillage practices. Generally, farmers tend to regard healthy soils as being those that produce healthy crops, with only a secondary consideration given to the absence of soil degradation problems such as poor soil structure and nutrient deficiency (Lobry De Bruyn & Abbey, 2003).

Bennett & Cattle (2013) found that a majority of farmers surveyed in Lachlan and Macquarie Valleys in New South Wales, Australia, agreed that if they managed their soils correctly, they may not see an increase in yearly production, but longevity of production will be better. While the overall attitude towards soil health management was positive, there was a perceived irrelevance of some specific soil health indicators which “may actually be caused by a farmer's unwillingness to suggest they do not understand something; that is, ‘I don't know what it is, therefore it probably isn't important.’”(J. M. L. Bennett & Cattle, 2013). Similarly, Carlisle (2016) argued that “farmers’ most commonly cited motivations for adopting soil health practices were agronomic, and focused on building long-term soil health”. Other studies show that land owners saw the greatest benefits of these practices in terms of their potential to build soil organic matter, reduce erosion, control weeds, and reduce soil compaction (Bergtold et al., 2012; Sackett, 2013; Singer et al., 2007). Thus, how much value farmers place on soil health characteristics would determine in part whether they choose to adopt no till on a parcel of land or not.

Closely related to the value farmers place on soil health are farmers’ beliefs of how current conservation practices affect soil health and other state variables in the next period $E\left(\mathbf{x}_{t+1}(1)-\mathbf{x}_{t+1}(0)\right)$. It has been scientifically proven that conservation tillage when done appropriately and taking into cognizance spatial and environmental scales, increases soil organic carbon, reduces soil compaction, decreases soil erosion and improves overall soil health (Lehman et al., 2015). However whether individual farmers believe this to be the case in respect to their specific farms play a large role in deciding whether they would adopt soil conservation practice or not. If a farmer for example is resistant to change and prefers to stick to the status quo – the ways of his forefathers (Sheth & Stellner, 1979) and does not think that no-till have beneficial effects on soil, he is unlikely to adopt.

Nonetheless, the evidence is overwhelming that the value of soil health and farmers’ beliefs about the impact of no-till on soil health plays a critical factor in determining whether he will adopt conservation tillage practice. This reveals the importance of education and enlightenment of farmers about the value of soil health characteristics and how no-till contributes to better soil health. Extension agents, mass media and other concerned educational outlets have a huge role to play in enlightening farmer groups, especially in targeting individuals that might be resistant to new technologies so that they can eviscerate deeply entrenched unhealthy and unproductive farming behavior in favor of sustainable practices.

7. Farmer's risk aversion and effect of adoption on variance in profits

The effect of conservation tillage on the variance of a farmer's profits is captured by the terms $u_{\pi\pi}$ and $\left[Var\left(\pi \mid z_t^c = 1, \mathbf{x}_t\right) - Var\left(\pi \mid z_t^c = 0, \mathbf{x}_t\right)\right]$ in equation 3. There is a wonderful interplay of the sign and magnitude of these two related factors. If $u_{\pi\pi}$ is negative (i.e. the farmer is risk averse) and NT is a variance-reducing practice, this portion of equation 3 makes NT more attractive to the farmer. Of course, the magnitude of such effects would depend on the level of risk aversion of the farmers and the size of the difference between variance of profits with and without the conservation tillage.

Risk is a very important component in farmers' "decision-making process due to the variability and uncertainty of agricultural production" (Boyer et al., 2015; Fan et al., 2020; Larson et al., 2001; Moschini & Hennessy, 2001). Research has shown that uncertainty is a "key barrier to the wide adoption of conservation practices" largely because it distorts the projected outcomes of agricultural operations (Lee & McCann, 2019; Singer et al., 2007; Wade et al., 2015). Apart from weather and price uncertainty, "the economic consequences of producers' actions are also influenced by the uncertainty" in attempting a novel conservation practice (Wade et al., 2015). These factors largely "result in the difficulties of predicting yield and income of different farming practices" (Lien et al., 2007) which may result in risk averse farmers sticking to the status quo.

Researchers have argued that incentives to invest in soil technologies may substantially dwindle when such management decisions have stochastic properties. With regard to site specific technologies (SSTs) for example, Isik and Khanna (2003) concluded that ignoring uncertainty and risk aversion in economic analysis would overestimate the economic and environmental benefits of SSTs and underestimate the subsidy required to induce adoption. Indeed, the interplay of risk and the farmers' capacity to bear risk could be an important conditioning factor in the adoption decision (Shively, 2001). Thus, farmers may only be motivated to adopt conservation practices if the expected gains exceed the perceived uncertainty (Bergtold et al., 2012)

In regard to risk aversion, farmers especially those who are risk averse do not accept to engage in this experience or endure the likely failure. Empirical investigations of risk in agriculture indicates that farmers express varying degrees of risk aversion and that their risk attitudes may strongly affect their economic behavior. With respect to differences in the variance of profits, it was found in the Philippines that income risk associated with soil conservation measures can discourage adoption especially by resource constrained farmers (Shively, 2001). During the early years of no-till, yield may drop because of lack of mastery regarding weed control, the incompatibility of no-till driller to the nature of soils or due to other intricate dynamic processes (Rouabhi et al., 2018). Thus both risk aversion and variance in profits are key elements to consider in this context. In an economic risk analysis of no-till management for rice-soybean rotation system in Arkansas using simulation, results showed that risk neutral and risk averse rice producers would prefer no-till over conventional till managements in the two-year rice-soybean rotation and that no-till soybeans contribute greatly to the overall profitability of the rotation (Hristovska et al., 2013). This simulation result suggests that $u_{\pi\pi}\left[Var\left(\pi \mid z_t^c = 1, \mathbf{x}_t\right) - Var\left(\pi \mid z_t^c = 0, \mathbf{x}_t\right)\right] > 0$ for their study implying that for risk averse farmers ($u_{\pi\pi} < 0$), variance in profits for no-till was less than that for tillage which makes the term additive to total utility.

However, in an experimental study on the willingness of farmers to take risks (which relates the subjective risk preferences to actual soil conservation decisions), Teklewold and Kohlin (2011) found that a "high degree of risk aversion significantly decreases the probability of adopting soil conservation. This implies that reducing farmers' risk exposure could promote soil conservation practices and thus more sustainable natural resource management."

From the foregoing, there is strong evidence that $u_{\pi\pi} < 0$ implying that farmers are generally risk averse. But there is mixed evidence as to whether the variance in profits from no-till is lower than that from conventional tillage due to contrasting findings. More research need to be done in this area in order to better understand how variance in profits are affected by tillage decisions and how farmers risk preferences interplay with it

8. Conclusion

There is widespread concern about soil health and public support for improved soil conservation with specific interest in increasing the adoption of conservation tillage. Bio-mulch to conserve soil moisture, improved control of pests and diseases, increased organic matter, improved soil structure and increased soil carbon storage are just but a few of the benefits derivable from minimum or no tillage. Using a dynamic programming model, we showed that many factors affect a farmer's decision to adopt soil conservation. This decision affects not just the farmer's current benefits, but also future utility during the planning horizon. Using a Taylor series approximation, we identify seven separate effects that might play an important role in the decision: profitability of the soil conservation decision, non-monetary utility derived from higher yields, benefits derived from government payments, ‘soil stewardship, environmentalism and social pressure’, probability of securing lease and effect of the conservation decision on his future access to land, the value the farmer places on soil health characteristics and his belief that doing no-till actually improves soil health and the farmer’s risk aversion and belief that adopting will lead to a change in variance of profits.

As we have shown, there has been research that has studied each of these separate effects. In most cases there is no general conclusion. For example, some studies have found NT to be yield-increasing, while others have found the opposite. Certainly, there is significant variation over space and between farmers. We believe that this theoretical framework will be valuable to empirical research and extension activities. An appreciation of the multiple factors that enter into a farmer’s calculation is critical to answering the important question for both researchers and policy makers: Why do farmers choose to adopt or not adopt a soil conservation innovation?

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APPENDIX

An Operational Model

The farmer’s expected utility in this period is a function of profits on the field, $\pi(\cdot)$, government payments in the current period, g_t, any non-market benefits associated with adopting the conservation practice, and the yield in the current year, y_t, which enters into profits and separately to the extent that the farmer obtains non-financial benefits. We assume that profit is stochastic, captured by the random variable ε_t, with mean zero so that

$$E_\varepsilon \pi\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right) = \pi\left(z_t^c, \mathbf{x}_t, 0\right).$$

Define the certain value, $\bar{\tilde{V}}\left(\mathbf{x}_t, z_t^c\right)$, as

$$\bar{\tilde{V}}\left(\mathbf{x}_t, z_t^c\right) = \tilde{V}\left(\mathbf{x}_t, z_t^c \mid \varepsilon = 0\right) = u\left(\pi\left(z_t^c, \mathbf{x}_t, 0\right), g_t, z_t^c, y_t\left(z_t^c, \mathbf{x}_t, 0\right)\right) + \beta P_L V\left(\mathbf{x}_{t+1}\left(z_t^c, \mathbf{x}_t, 0\right)\right)$$

That is, the value to the farmer of adopting the practice z_t^c if all uncertainty in the current period were eliminated. Our goal is to identify the benefits to the farmer of adopting the conservation, and this can be decomposed as follows:

$$\begin{aligned}&\tilde{V}\left(\mathbf{x}_t, z_t^c = 1\right) - \tilde{V}\left(\mathbf{x}_t, z_t^c = 0\right)\\ &\qquad = \left[\bar{\tilde{V}}\left(\mathbf{x}_t,1\right) - \bar{\tilde{V}}\left(\mathbf{x}_t,0\right)\right] + \left[\tilde{V}\left(\mathbf{x}_t,1\right) - \bar{\tilde{V}}\left(\mathbf{x}_t,1\right)\right] - \left[\tilde{V}\left(\mathbf{x}_t,0\right) - \bar{\tilde{V}}\left(\mathbf{x}_t,0\right)\right].\end{aligned} \tag{1}$$

The first brackets in **Error! Reference source not found.** captures the difference in the certain value when z_t^c=0 and z_t^c=1. The second and third brackets capture the difference between the true value, $\tilde{V}\left(\mathbf{x}_t, z_t^c\right)$, and certain utility functions with and without the conservation practice.

Equation **Error! Reference source not found.** can then be written using a Taylor series expansion in which we hold $\mathbf{x}_t$ constant and assume that except for $u_{\pi\pi}$, all other second derivatives are zero, and $u_{\pi\pi\pi}$=0.

First consider the difference between $\tilde{V}\left(\mathbf{x}_t, z_t^c\right)$ and the certain utility, $\bar{\tilde{V}}\left(\mathbf{x}_t, z_t^c\right)$:

$$\begin{aligned}&\tilde{V}\left(\mathbf{x}_t, z_t^c\right) - \bar{\tilde{V}}\left(\mathbf{x}_t, z_t^c\right) \approx\\ &\qquad E\left[u_\pi \cdot \left(\pi\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right) - \pi\left(z_t^c, \mathbf{x}_t, 0\right)\right) + u_y \cdot \left(y\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right) - y\left(z_t^c, \mathbf{x}_t, 0\right)\right)\right]\\ &\qquad + \beta\left[P_L E \frac{\Delta V\left(\mathbf{x}_{t+1}\right)}{\Delta \mathbf{x}_{t+1}}\left(\mathbf{x}_{t+1}\left(z_t^c; \varepsilon_t\right) - \mathbf{x}_{t+1}\left(z_t^c; 0\right)\right)\right]\\ &\qquad + \frac{1}{2} E u_{\pi\pi} \cdot \left(\pi\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right) - \pi\left(z_t^0, \mathbf{x}_t, 0\right)\right)^2.\end{aligned} \tag{2}$$

With some loss of generality, we will assume that $\pi(\cdot)$, $y(\cdot)$ and the state equations, $\mathbf{x}_{t+1}\left(z_t^c; \varepsilon_t\right)$ are linear in ε_t so that the $E\pi\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right) = \pi\left(z_t^c, \mathbf{x}_t, E\varepsilon_t\right) = \pi\left(z_t^c, \mathbf{x}_t, 0\right)$ and similarly for $y(\cdot)$ and $\mathbf{x}_{t+1}\left(z_t^c; \varepsilon_t\right)$. With that assumption, the second and third lines in **Error! Reference source not found.** equal zero and the equation can be rewritten

$$\tilde{V}\left(\mathbf{x}_t, z_t^c\right) - \bar{\tilde{V}}\left(\mathbf{x}_t, z_t^c\right) \approx \frac{1}{2} u_{\pi\pi} \cdot E\left(\pi\left(z_t^c, \mathbf{x}_t, \varepsilon_t\right) - \pi\left(z_t^0, \mathbf{x}_t, 0\right)\right)^2, \tag{3}$$

and $E\left(\pi\left(z_t^c,\mathbf{x}_t,\varepsilon_t\right)-\pi\left(z_t^0,\mathbf{x}_t,0\right)\right)^2=Var\left(\pi\mid z_t^c,\mathbf{x}_t\right)$. Hence, the second and third brackets in **Error! Reference source not found.** can be written as

$\frac{1}{2}u_{\pi\pi}\left(Var\left(\pi\mid z_t^c=1,\mathbf{x}_t\right)-Var\left(\pi\mid z_t^c=0,\mathbf{x}_t\right)\right)$

What remains to be approximated in **Error! Reference source not found.**, therefore, is $\bar{\bar{\tilde{V}}}\left(\mathbf{x}_t,1\right)-\bar{\bar{\tilde{V}}}\left(\mathbf{x}_t,0\right)$, the difference in the certain utility functions attributable to the change in the conservation practice. In this case the Taylor series expansion yields

$$\begin{aligned}
&\bar{\bar{\tilde{V}}}\left(\mathbf{x}_t,1\right)-\bar{\bar{\tilde{V}}}\left(\mathbf{x}_t,0\right)\approx\\
&\qquad+E\left[\begin{array}{r}u_\pi\cdot\left(\pi\left(1,\mathbf{x}_t,0\right)-\pi\left(0,\mathbf{x}_t,0\right)\right)+u_g\cdot\left(g\left(1\right)-g\left(0\right)\right)+u_z\cdot\left(1-0\right)\\
+u_y\cdot\left(y\left(1,\mathbf{x}_t,0\right)-y\left(0,\mathbf{x}_t,0\right)\right)\end{array}\right]\\
&\qquad+\beta\left[\frac{\partial P_L\left(\cdot\right)}{\partial z}\left(1-0\right)\cdot EV\left(\mathbf{x}_{t+1}\left(0\right)\right)+P_L E\,\frac{\Delta V\left(\mathbf{x}_{t+1}\right)}{\Delta\mathbf{x}_{t+1}}\left(\mathbf{x}_{t+1}\left(1\right)-\mathbf{x}_{t+1}\left(0\right)\right)\right]\\
&\qquad+\frac{1}{2}Eu_{\pi\pi}\cdot\left(\pi\left(1,\mathbf{x}_t,0\right)-\pi\left(0,\mathbf{x}_t,0\right)\right)^2.
\end{aligned}\tag{4}$$

The terms in the first square brackets capture the immediate and linear effects of a change in z_t^c on the farmer's utility this year. The terms in the second square brackets capture the effect on the farmer's future welfare, taking into account both the effect that the practice might have on the probability that the farmer can have access to the land in the next period, and the effect of the practice on the range of soil health attributes, where $\Delta V\left(\mathbf{x}_{t+1}\right)/\Delta\mathbf{x}_{t+1}$ refers to the vector of partial derivatives. The last line captures the adjustment that must be made to our approximation due to the assumed concavity of the utility function with respect to profits.

We can now write out the complete approximation of the value to the farmer of adopting the conservation practice, substituting **Error! Reference source not found.** and **Error! Reference source not found.** into **Error! Reference source not found.**:

$$
\begin{aligned}
&\tilde{V}\left(\mathbf{x}_t, z_t^c = 1\right) - \tilde{V}\left(\mathbf{x}_t, z_t^c = 0\right) \approx \\
&\qquad + E\left[\begin{aligned} &u_\pi \cdot \left(\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right) + u_g \cdot \left(g\left(1\right) - g\left(0\right)\right) + u_z \cdot \left(1 - 0\right) \\ &\qquad\qquad\qquad\qquad + u_y \cdot \left(y\left(1, \mathbf{x}_t, 0\right) - y\left(0, \mathbf{x}_t, 0\right)\right)\end{aligned}\right] \\
&\qquad + \beta\left[\frac{\partial P_L\left(\cdot\right)}{\partial z}\left(1 - 0\right) \cdot EV\left(\mathbf{x}_{t+1}\left(0\right)\right) + P_L E \frac{\Delta V\left(\mathbf{x}_{t+1}\right)}{\Delta \mathbf{x}_{t+1}}\left(\mathbf{x}_{t+1}\left(1\right) - \mathbf{x}_{t+1}\left(0\right)\right)\right] \\
&\qquad + \frac{1}{2} u_{\pi\pi} \cdot \left[\pi\left(1, \mathbf{x}_t, 0\right) - \pi\left(0, \mathbf{x}_t, 0\right)\right]^2 \\
&\qquad + \frac{1}{2} u_{\pi\pi} \cdot \left[Var\left(\pi \mid z_t^c = 1, \mathbf{x}_t\right) - Var\left(\pi \mid z_t^c = 0, \mathbf{x}_t\right)\right].
\end{aligned}
$$