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# An analysis of the joint adoption of water conservation and soil conservation in Central Chile

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ABSTRACT

Studies reveal that 80% of the world's agricultural land is showing signs of moderate levels of soil erosion. On the other hand, it is a fact that water is becoming a more scarce resource jeopardizing food security. Thus, conserving both water and soil are two of the most pressing issues in international agriculture and food production. This article examines the impact of natural, social, human, and financial capital variables on the adoption of water conservation and soil conservation (WC&SC) as a joint decision, using a bivariate model. Socioeconomic and production information was collected by surveying a random sample of 319 small-scale irrigated farms in central Chile in 2005. The results suggest that the adoption of WC&SC is a joint and complementary decision. The results also indicate that farm size, production system, access to credit, and government incentives are important variables associated with the adoption of conservation measures. From a policy stand point, the institutions in charge of providing incentives and administering instruments intended to promote conservation should take into account the complementarity of the adoption decisions. Program designs should incorporate incentives that jointly promote the adoption of WC&SC in order to enhance effectiveness.



## Introduction

Land degradation consists of the deterioration of soil quality and thus of its productive capability. Erosion is a key culprit in land degradation and can play a major role, since it is often of significant magnitude, irreversible and, in extreme cases, creates the total loss of soil (Hugo, 2008). Rapid erosion in Chile is associated primarily with farming practices that degrade the soil such as compaction, and the loss of organic matter and soil structure. Erosion is a concern given the hilly landscape of the country particularly in areas with high annual precipitation where much of the rain falls in short periods of time (Ellies, 2000). According to the international literature, 70–80% of the land dedicated to agricultural activities worldwide exhibits moderate to severe erosion (Blaike and Brookfield, 1987; Pimentel et al., 1995). Soil erosion is a challenging issue not only because it leads to productivity losses, but also because it is strongly linked to desertification and rural poverty (Barbier and Bishop, 1995; Ruben et al., 2004).

The causes of land degradation are varied and complex and can be grouped in three major categories: (1) climatic (e.g., rain fall, drought); (2) bio-geophysical (e.g., slope, soil type); and (3) managerial (e.g., farmer education, experience, access to extension services). These three groups of variables are critical in determining the likelihood and speed of soil erosion (Muchena et al., 2005). Many traditional agricultural practices contribute to soil degradation (Solís et al., 2009) while technologies designed to improve or conserve soil are not always adopted, even when their usefulness has been demonstrated (Amsalu and de Graaff, 2007). Furthermore, reduced productivity is usually mitigated in the short run with intensive use of inputs, which leads to additional degradation problems in the longer run (Solís and Bravo-Ureta, 2005). The severity of current degradation has inspired significant efforts to develop and promote the adoption of conservation strategies. However, the results are not always positive, and soil degradation continues to be a major problem worldwide (Pimentel et al., 1995).

In addition, irrigation water makes an important contribution to agricultural productivity and food security, but it is becoming an increasingly scarce resource (FAO, 1992; Bruinsma, 2009). This growing scarcity becomes even more significant in a context of climate change where global precipitation patterns are already altered (Reilly et al., 2007). This issue is critical considering that the productivity of 82% of the world's arable land depends on precipitation (Schultz et al., 2005). In areas where precipitation might decline, agriculture would face growing competition for water from higher-valued uses such as domestic, industrial and hydropower—all of which are rising. Thus, the agricultural sector will need to produce more food with less water.

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Dealing with expected water shortages represents an important technological and policy challenge. The careful management and increased efficiency of irrigation water is a relevant component of any plan of action that helps to understand the benefits of irrigation and conservation. Such benefits include higher land productivity and increased yields, a lower risk of crop failure, and increased year-round farm and nonfarm employment (Hussain and Hanjra, 2004).

Despite the potential complementarity of water conservation and soil conservation (WC&SC), very few studies have modeled the determinants of farm-level decisions to conserve water and soil simultaneously, and no such study has been carried out in Chile. Most of the literature treats the adoption WC&SC as separate decisions (Staal et al., 2002; Kim et al., 2005; Anley et al., 2007; Calatrava-Leyva et al., 2007; Kabubo-Mariara, 2007). Another approach, which depicts these decisions as interdependent, uses multivariate Probit regression models to estimate the adoption of different conservation strategies (Marenya and Barrett, 2007).

The U.S. Environmental Protection and Agency (1997) defines WC&SC as managerial, vegetative and structural practices to reduce the loss of soil and water, respectively. Several WC&SC strategies are described by Lee (2005) and analyzed by Knowler and Bradshaw (2007). Natural resource conservation has been found to have a positive impact on the productivity of annual crops (Gupta and Seth, 2007) and even to increase farm income (Bravo-Ureta et al., 2006). Limited evidence from Chile indicates that the implementation of crop rotations, minimum tillage and the use of legumes have improved soil quality and increased crop yields over time (Vidal et al., 2002). Considering that conservation has beneficial effects in the long run while possibly increasing profitability in the short run, gives rise to the following questions: what are the factors promoting or limiting the adoption of such strategies; and is the WC&SC a joint or an independent decision?

In economic terms, farmers adopt technologies and conservation strategies that they perceive to be profitable (Ellis, 1993; de Graaff et al., 2008); however, socioeconomic, cultural, and natural resource factors affect the rate at which farmers adopt conservation strategies (Lapar and Pandey, 1999; Soule et al., 2000). Moreover, the process of adopting interrelated conservation strategies is more complex than the decision to adopt a single technology, such as use of fertilizers or an improved seed variety. The single decision is usually based on short-term profitability considerations, while interrelated adoption implies a more substantial and longer-lasting change in farming conservation (Caswell et al., 2001; Boyd et al., 2000).

The objective of this paper is to contribute to the literature on resource conservation by analysing the factors that influence the simultaneous adoption of WC&SC using a bivariate modeling approach. The results could help to improve the understanding of farmers' behavior regarding conservation, and therefore help the development of incentives and/or instruments focusing on soil and water programs. More generally, the analysis will help to fill the gap that exits in the literature concerning the drivers of adoption of conservation in the country.

Despite the prominence of agricultural production in the country's economy, Wandel and Smithers (2000) point out that the relevant factors associated with adoption have a high degree of locational and technological specificity. Therefore, for Chilean policy makers and research institutions it is important to have a localized understanding of the factors that influence the adoption of WC&SC.

The rest of the paper is organized as follows: "Methodological framework" section describes the methodological framework; "Materials and methods" section discusses the study area, the data and the empirical model. "Results and discussion" section includes the results. "Policy implications" section contains policy implications and the final section is dedicated to concluding remarks.

## Methodological framework

Utility maximization theory has often motivated the methodological framework used to study technology adoption (e.g., Rahm and Huffmann, 1984; Adesina and Zinnah, 1993). According to this theory, a new technology will be adopted if the expected utility ($U$) derived from its use is higher than that of the current technology. Since $U$ is not directly observable, the model can be expressed as a binary choice in terms of observable adoption or non-adoption, which implies the use of a Probit or Logit model (e.g., Lapar and Pandey, 1999; Feder et al., 1985; Foltz, 2003).

The underlying $U$ function of the $i$th farmer, expressed in terms of farm and farmer-specific attributes, $X$, and a disturbance term having a mean of 0, can be written as:

$$U_{ij} = \beta_i(X_i) + \varepsilon_{ij} \quad j = 1, 0 \quad i = 1, 2, \ldots, n \tag{1}$$

where $X_i$ is a vector of explanatory variables and $\beta_i$ is a vector of parameters. Adoption of the new technology ($j = 1$) by the $i$th farmer occurs when $U_{i1} > U_{i0}$. According to Greene (2008), the bivariate Probit model, which considers two dichotomous decisions simultaneously, is a natural extension of the individual Probit model that features only one decision and a single equation. In our case, the decisions are the adoption/non-adoption of soil conservation, denoted by $s$, and of water conservation, denoted by $w$. In the model specification $s, w = 1$ for adoption and $s, w = 0$ for non-adoption, and the disturbance terms of the two equations can be correlated. The specification of the bivariate Probit model, following Greene (2008), is given by:

$$s = \beta_s x' + \varepsilon_s$$

$$w = \beta_w x' + \varepsilon_w \tag{2}$$

$$E[\varepsilon_s, \varepsilon_w] \sim \text{BVN}[0, 0, 1, 1, \rho]$$

where $E(\varepsilon_s) = E(\varepsilon_w) = 0$, $Var(\varepsilon_s) = V(\varepsilon_w) = 1$, $Cov(\varepsilon_s, \varepsilon_w) = \rho$ and the distribution is bivariate normal. Thus, the bivariate Probit model is a Seemingly Unrelated Regression (SUR) specification, where it is assumed that all regressors are exogenous, and estimation is done using maximum likelihood (Greene, 2007).

This approach has been used in explaining chemical input use, such as the joint adoption of fertilizer and pesticides (Nkamleu and Adesina, 2000), the adoption and dis-adoption of technologies as a sequential and conditional process (Amsalu and de Graaff, 2007; Neill and Lee, 2001), and the adoption of improved groundnut varieties along with chemical fertilizer (Thuo et al., 2013). In the first two studies, $\rho$ was found to be significant, which indicates that the error terms across equations are correlated. In the present study, we argue that the adoption of soil conservation is likely to condition positively the decision to adopt water conservation, and vice versa; thus, treating these decisions separately would generate biased parameter estimates and thus we hypothesize that $\rho$ is significant and positive.

Once the bivariate model is estimated, the next step is to consider the Marginal Effects (MEs) of the covariates. According to Greene (1996), the marginal means reported for the model assume that soil and water adoption are equal to 1, as follows:

$$E[s|w = 1, x_s, x_w] = \frac{\text{Prob}[s = 1|w = 1, x_s, x_w, \rho]}{\text{Prob}[w = 1|x_s]} \tag{3}$$

Then, the conditional mean for these two models would be identical:

$$E[s\,|w\; = 1] = \frac{\Phi_w[\alpha_s, \alpha_w, \rho]}{\Phi(\alpha_w)} \tag{4}$$