

Efficient use of Water Resources in Vineyards: A Recursive joint Estimation for the Adoption of Irrigation Technology and Scheduling

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Abstract Water constraints are becoming a major restriction for different economic sectors. The agricultural sector is one of the most affected, but according to experts, the use of irrigation technologies and scheduling can keep productivity high while diminishing the use of water resources. Although irrigation technology is available, for various reasons the rate of adoption is rather low. This article uses a recursive bivariate probit model to examine the impact of social, human, and physical capital on the adoption of irrigation technology and scheduling. The study was conducted in vineyard farms in the Maule and O'Higgins regions of Chile, from which a sample of 452 large, medium, and smallholders was drawn. The average planted area is 37 hectares, ranging from 0.5 to 810 hectares. The adoption rate of irrigation technology is 43 % and for scheduling instruments, 23 %. Results show that adopting irrigation technology increases the chance of adopting scheduling by 31 % and that these adoption decisions are jointly made. While size of the vineyard is relevant in irrigation technology adoption, it is not for scheduling and, in contrast, the use of the Internet is relevant for adopting scheduling but not for irrigation technology. A relevant result is that networks and trust are important factors in explaining the adoption of both technologies.

Keywords Technology adoption · Scheduling · Recursive bivariate probit · Irrigation

1 Introduction

Water availability is of increasing concern to agricultural production. On one hand, recent studies have demonstrated that climate change has had a significant impact on rainfall cycles, altering the occurrence of droughts and flooding, which in turn affect agricultural

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yields in all geographic areas of the world (Liu et al. 2010; Heumesser et al. 2012). On the other hand, increasing population pressure is expected to divert from 8 % to 15 % of the water used today in agriculture, which currently represents around 65 % of the total, to domestic use and other economic sectors (Chartzoulakis and Bertaki 2015; Hess and Knox 2013). Chile is not exception in this regard, and projections for the Central-South region anticipate a decrease in precipitation of up to 40 % and a rise in temperatures between 2 °C and 4 °C in the next 40 years (Chilean Ministry of Agriculture 2013). For example, in the Maule region¹, from 1870 to 2014, rainfall has diminished by 147.7 mm per year. For reference, in regard to this study, the average rainfall in Talca, the principal city of the Maule region, is 700 mm a year. Also, droughts have increased in the last 10 years and have been so severe in some villages of the region that they have even affected water availability for citizens.² A recent study done in the Maule region covering a variety of irrigated and dry-land agro-ecological areas shows decreasing rainfall and increasing variability within years during the last three decades, a trend that farmers also perceive (Roco et al. 2014).

In this scenario, there is a need for a more efficient use of water resources, where cooperation of users appears to have an impact on water sustainability (El Chami and Karaa 2012). Experts have ranked the use of irrigation technology as one of the most effective ways to adapt to climate change, preventing water scarcity and helping to increase water conservation (Roco et al. 2014; Jara-Rojas et al. 2013). Moreover, irrigation technology has proved to be effective in increasing productivity as well as reducing risk (Heumesser et al. 2012; Chandran and Joseph 2015; Alam et al. 2012). Several studies have analyzed the adoption of irrigation technologies (Alcon et al. 2011; Bjornlund et al. 2009; Abdulai et al. 2011; Namara et al. 2007), but fewer have looked at the adoption of irrigation scheduling (Bhatti and Patel 2015; Jara-Rojas et al. *in press*; Montoro et al. 2011).

To the best of our knowledge, however, no studies have focused on the joint adoption of irrigation technology and scheduling. We understand irrigation technology as the irrigation system, such as drips and sprinklers, and scheduling as programming the frequency and timing of irrigation so as to reach higher yields. Chartzoulakis and Bertaki (2015) point out that making decisions on irrigation timing and quantity is complex due to the many variables involved, namely, type of soil, temperature, and precipitation, all of which are subject to high uncertainty, which implies using specific instruments that capture meteorological data and plant and soil conditions to develop an appropriate irrigation schedule (Chartzoulakis and Bertaki 2015; Naor 2006; Bhatti and Patel 2015). Due to the complexity of irrigation scheduling, in our case, we measure the adoption of scheduling as the adoption of instruments for programming.³ The objective of this paper is twofold: first, to determine the factors explaining irrigation technology adoption and adoption of scheduling by vineyard farmers. Our hypothesis is that these are complementary and, even more, that the adoption of irrigation technology has a positive effect on the adoption of scheduling. The second objective is to determine how social capital, defined here as networks and trust, affects the adoption of such technologies. In particular, since scheduling requires a learning process, social capital becomes a relevant factor in adoption. Indeed, in the literature some authors concur that trust and networks lead to an easier learning process (Eastwood et al. 2012; Solano et al. 2003). In classical economic theory various factors are

¹The Maule region is located in Central-South Chile (35° 25'36''S, 71° 39'78''O), and its main agricultural activity is fruit and vineyard production.

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³Instruments include metrological stations, soil or plant sensors, and pan evaporation.

understood to influence a farmer's adoption decision. Besides economic aspects like farm size, land ownership or credit access, human capital also plays an important role (Handschuh et al. 2013; Abdulai and Huffman 2014; Genius et al. 2014; Abdulai et al. 2011; Foster and Rosenzweig 2010). In addition, the importance of social capital in understanding behavior and the decision making process has also been acknowledged (Lollo 2012; van Rijn et al. 2012; Cramb et al. 2004). Although neither a generally accepted definition of social capital exists (Beugelsdijk and Smulders 2004), nor a single indicator to measure it, generally speaking, the main benefit from social capital is seen in the information flows provided by networks and trust that can filter, concentrate, and legitimate this information (Chalupnick 2010; Bandiera and Rasul 2006; van Rijn et al. 2012). As previously stated, a consequence of a more highly legitimated information flow is that it facilitates the learning process. To achieve our objectives, a recursive bivariate probit model is used to estimate jointly the adoption of irrigation technology and scheduling and, more specifically, to quantify the impact of irrigation technology adoption on scheduling. Recursive models have been applied in agricultural technology adoption to deal with endogenous complementary variables (Frondel et al. 2008; Di Falco and Van Rensburg 2008; Thuo et al. 2014). In this article we use as a case study irrigation adoption in vineyards in the Maule and O'Higgins regions of Chile. Grapes is one of the most important crop in the Chilean agricultural sector and also in the regions of this study, accounting for 73 % of the national total, or 128,638 ha. According to (Acevedo-Opazo et al. 2010), increasing Chilean wine production and exports have pushed this sector to make relevant changes in productive strategies, especially producing high quality grapes, which are very sensitive to water stress management (Pellegrino 2005; Ojeda et al. 2015). Many studies of vineyards during the last two decades have shown the effect of irrigation over different phenological stages and its relationship to grape composition and quality attributes (Dry and Loveys 1998; Pellegrino 2005; Ezzhaouani et al. 2007). Hence, studying irrigation practices, in terms of technology and optimal use, is still relevant for researchers and policy makers. The paper is structured as follows. Section 2 describes the methodology, study area and data sources used for the model estimation; the third section presents and discusses results; and the last section summarizes the most relevant findings and offers conclusions.

2 Methodology

2.1 Study Area and Data Source

The study area covers the O'Higgins and Maule regions in Central-South Chile (33° 50' and 36° 33'S). Both regions belong to the central valley of the country, in the heart of fruit and vineyard production. This area has a temperate Mediterranean climate, with a six-month dry season (September through February) and a rainy winter, with precipitation around 700 mm annually (CIREN 2010; 2011). The data used in this study was generated at the farm-level from a sample of 452 observations across 16 municipalities in the Maule and O'Higgins regions. The criteria for selecting the municipalities were two: importance in terms of vineyard production, and municipalities⁴ in which at least 30 % of the land is irrigated, which yielded a sample of 16 municipalities. The sample was stratified by municipality, and the

⁴The municipalities were, in order of number of surveyed producers: San Javier, Sagrada Familia, Curicó, Nancagua, Villa Alegre, Santa Cruz, Talca, Palmilla, San Clemente, Peralillo, Río Claro, Requinoa, Chimarrongo, Maule, San Vicente, and Peumo.

observations were grouped in three valleys that represent different climate and soil conditions: namely, Cachapoal/Colchagua, Curicó, and Maule (See Appendix A). To stratify the sample, we used as a reference the wine growing cadastral 2012 (ODEPA 2012). For the interviews, producers were selected in situ using as a rule that each interviewed producer had to be at least one km away from the next one. Surveys were administered between October 2014 and March 2015. The questionnaire was composed of six different sections. In the first section, farm structure and general demographic information (e.g. age, experience and educational level) were requested. The second part asked questions about irrigation issues, with knowledge of irrigation scheduling, instruments and information used, and hiring of advisers among the most relevant. The third section included questions to estimate the profitability of the vineyard with very specific data; and the last two sections aimed at evaluating trust and the individual’s respect for norms and intention to adopt, as well as their extension network.

2.2 Model Description

Traditionally, the decision to adopt a certain technology is driven by maximization of householder utility, as defined by Rahm and Huffman (1986) and Adesina and Zinnah (1993) in their seminal papers. Accordingly, a new technology ($j=I$) will be adopted by the i^{th} farmer, with $i=1, \dots, n$, if:

$$y_i^* = U_{iI} - U_{i0} > 0 \tag{1}$$

Although we cannot observe directly, we do observe the decision behind this maximization process, the binary variable of adopting or not scheduling (SCH) and irrigation technology (IRR). Since the hypothesis is that irrigation technology adoption is endogenous with the adoption of scheduling, we defined a Recursive Bivariate Probit (RBP) model as follows:

$$SCH_i^* = (X_i, W_i, IRR_i^*) + \varepsilon_{SCHi} \quad SCH_i = 1 \text{ if } SCH_i^* > 0, 0 \text{ otherwise} \tag{2}$$

$$IRR_i^* = (X_i, Z_i) + \varepsilon_{IRRI} \quad IRR_i = 1 \text{ if } (IRR_i^*) > 0, 0 \text{ otherwise} \tag{3}$$

$$E[\varepsilon_{SCHi}] \sim BVN[0, 0, 1, 1, \rho] \tag{4}$$

Where

$$E(\varepsilon_{IRR}) = E(\varepsilon_{SCH}) = 0, \text{ Var}(\varepsilon_{IRR}) = \text{Var}(\varepsilon_{SCH}) = 1, \text{ Cov}(\varepsilon_{IRR}, \varepsilon_{SCH}) = \rho \tag{5}$$

In Eqs. (2) and (3), X_i , are explanatory variables common to both equations, while W_i and Z_i are specific variables included in Eq. (2) and (3), respectively. Also, two dichotomous decisions are estimated simultaneously. In the model specification IRR , $SCH = 1$ for adoption and IRR , $SCH = 0$ for non-adoption, and the disturbance terms of the two equations can be correlated (ρ). Following Castello (2012), the Wald test is used for both models to evaluate the hypothesis $H_0: \rho = 0$. In the RBP model, if the ρ parameter is non-significant, this indicates that the adoption of irrigation technology (IRR) is exogenous and, thus, the two decisions are not jointly made, requiring no additional considerations in the estimation procedure.

The model considers four possible outcomes: *i*) a vineyard farmer who adopts scheduling and irrigation technology ($SCH = 1, IRR = 1$); *ii*) a vineyard farmer who adopts scheduling but does not adopt irrigation technology ($SCH = 1, IRR = 0$); *iii*) a vineyard farmer who does not adopt scheduling but adopts irrigation technology ($SCH = 0, IRR = 1$); and *iv*) a vineyard farmer who adopts neither scheduling nor irrigation technology ($SCH = 0, IRR = 0$).

This approach has been used in agriculture to explain conservation and cooperation (Di Falco and Van Rensburg 2008), environmental management and innovation (Frondel et al. 2008), the adoption of improved groundnut varieties along with chemical fertilizer (Thuo et al. 2014), and the adoption of soil conservation and water conservation (Jara-Rojas et al. 2013).

The marginal effects of the variables analyzed were derived from the parameters of both adoption equations, in this case using a standard normal density function, as Greene (2003) explains

$$(\partial E[y|x])/\partial x = \phi(x'\beta)\beta \tag{6}$$

$$\begin{aligned} SCH_i = & \alpha_0 + \alpha_1 IRR_i + \alpha_2 EDUC_i + \alpha_3 EXP_i + \alpha_4 INT_i + \alpha_5 ADV_i + \alpha_6 SIZE2_i \\ & + \alpha_7 SIZE3_i + \alpha_8 VALL2_i + \alpha_9 VALL3_i + \alpha_{10} NET_i + \alpha_{11} TRUST_i \\ & + \alpha_{12} OWN_i + \varepsilon_{SCH_i} \end{aligned} \tag{7}$$

$$\begin{aligned} IRR_i = & \beta_0 + \beta_1 EDUC_i + \beta_2 EXP_i + \beta_3 INT_i + \beta_4 ADV_i + \beta_5 SIZE2_i + \beta_6 SIZE3_i \\ & + \beta_7 VALL2_i + \beta_8 VALL3_i + \beta_9 SPILL_i + \beta_{10} TRUST_i + \beta_{11} OWN_i + \varepsilon_{IRR_i} \end{aligned} \tag{8}$$

Table 1 Variable description and statics

Variable	Description	Percentage
IRR	Adopt irrigation technology = 1; 0 otherwise.	43.40 %
SCH	Adopt instruments for scheduling = 1; 0 otherwise.	23.00 %
INT	Use of Internet for meteorological data = 1; 0 otherwise.	71.00 %
ADV	Have consultant = 1; 0 otherwise.	37.60 %
VALL1	Cachapoal and Colchagua valley.	33.60 %
VALL2	Curicó valley.	21.50 %
VALL3	Maule valley.	42.30 %
OWN	Farm has one owner = 1; 0 otherwise.	55.80 %
SPILL	Percentage of producers that have IRR related total number acquaintances.	39.00 %
		Mean
EDUC	Number of years of education.	11.70
EXP	Years of experience.	28.70
AGE	Years old.	52.50
SIZE1	Hectares of vineyards, vineyards from 0 ha to 7.50 ha.	3.60
SIZE2	Hectares of vineyards, vineyards from 7.60 ha to 33 ha.	18.20
SIZE3	Hectares of vineyards, vineyards from 33.10 ha to 810 ha.	87.30
DIST	Minutes from the farm to the nearest village.	17.40
NET	Number of acquaintances (colleagues, friends).	16.50
TRUST	Factor component (Appendix B).	

3 Results and Discussion

3.1 Descriptive Statistics

In Table 1 we present a description of the variables used in the model, as well as the mean values and standard deviations for the whole sample. As can be observed, 43.3 % of the farmers in the sample adopted irrigation technologies, while only 23.0 % adopted scheduling, measured as the use of instruments for programming the frequency and time of water use.

The difference in adoption, which in the case of irrigation technology was almost double that of instruments for scheduling, can be understood by the incentives provided to adopt the technology. In Chile, in 1981 and 1985, the National Irrigation Commission (CNR) implemented two incentives to increase the irrigated area. The first was the Irrigation Development Law (*Ley de Fomento al Riego N^o 1,123, 1981*), which provides funding for major investment; and second, and more relevant for our study, the Investment Irrigation Law (*Ley de Fomento a Obras Menores de Riego N^o 18.450, 1985*), which provides farmers with a subsidy for infrastructure and improvement of irrigation (Ríos Brehm and Quiroz 1995). The CNR reported on its web page that since these Laws was implemented the area under pressurized irrigation has increased by more than 50 %. However, such the Investment Irrigation Law does not include subsidies for scheduling instruments. In this sense, a relevant question for policy makers is what is the impact of investment in irrigation scheduling, since it appears that irrigation efficiency could be improved if it is used correctly. Some initiatives have been taken to implement extension programs to promote the efficient use of irrigation technologies. One example is Irrigation Scheduling Service for Irrigation Water Optimization (SEPOR), a project whose main objective is developing and promoting an irrigation scheduling system. The results of the project show that training had a positive and high impact on adoption, while extension (direct intervention) had a minor effect. This result emphasizes the need for an adequate methodology to transfer knowledge and know-how to producers so that they can effectively use public resources (Jara-Rojas et al. [in press](#)).

Combining irrigation technology adoption and adoption of scheduling, as shown in Table 2, we observe that only 19.2 % of farmers adopt both technologies, while 52.9 % adopt neither. Also, just 3.8 % adopt scheduling without irrigation technology. The data allows us to infer that from the 43.3 % of farmers that adopt irrigation technology, almost half of them also engage in adoption scheduling suggesting that getting drip irrigation may have an impact on scheduling. This result supports our main hypothesis that irrigation technology is an endogenous variable with regard to adoption of scheduling.

Older farmers are expected to be more experienced in farming activities, in our case the average years of experience is 28.7 years. Looking at Table 2, the average experience of the farmers who do not adopt any of the technologies is 33.9 years compare to an average of 20-24 for those farmers who adopt at least one technology. The above shows that more experienced farmers are more reluctant to change, largely supported by the literature (Abdulai et al. 2011; Jara-Rojas et al. 2013). The educational level in the sample is 11.7 years of schooling, which corresponds to high-school level. The distribution of years of schooling reveals that 64.4 % of the sample have less than high-school level, while 35.6 % attain higher degrees. The trend shown in Table 2 with respect to average educational level reflects that the last group (non-adopters) has an average of three fewer years of education, a significant difference, at the 5 % confidence level, with respect to the other three groups, which is also consistent with the literature (Anley et al. 2007). On the other hand, 71.0 % use the Internet to acquire weather information. The literature regarding the use of Internet

Table 2 Descriptive statistics of the four combinations of dependent variables

Variable	IRRI and SCH (N= 87) 19.20 %	IRRI not SCH (N= 109) 24.10 %	SCH not IRRI (N= 17) 3.80 %	Neither (N= 239) 52.90 %
EDUC (year)	13.6 a	12.6 a	13 a	10.4 b
EXP (year)	20.3 a	24.9 a	22.9 a	33.9 b
INT (%)	97.7 a	77.1 ab	88.2 a	57.3 b
ADV (%)	73.6 a	41.3 b	41.2 b	22.6 b
OWN (%)	25.3 a	43.1 a	41.2 a	73.7 b
SIZE1 (%)	2.3 a	19.3 ab	35.3 bc	52.7 c
SIZE2 (%)	20.7 a	36.7 a	35.3 a	34.7 a
SIZE3 (%)	77.0 a	44.0 b	29.4 b	12.6 c
VALL1 (%)	57.5 a	27.5 b	41.2 ab	32.2 b
VALL2 (%)	14.9 a	22.9 a	23.5 a	23.0 a
VALL3 (%)	27.6 a	49.5 a	35.3 a	44.8 a
NET (n)	20.7 a	14.0 a	29.2 b	15.2 a
SPILL (%)	62.6 a	47.9 b	47.4 b	25.1 c

and information technologies is inconclusive. Our results are in line with Frisvold and Deva (2012) about the use of software in the horticultural sector. However, (Taragola and Van Lierde 2010) report a low use of Internet among producers in the same sector. Going back to Table 2, there is a clear trend showing that 97.7 % of the farmers who adopt both technologies use the Internet, contrasting with the 57.2 % of the farmers who do not adopt. Again, the difference between groups is significant at the 5 % confidence level, and, moreover, it is interesting to note that the use of Internet is also high (88.2 %) in the group that adopts scheduling but not irrigation technology. Since the use of scheduling requires also the use of meteorological information, this result reveals that the Internet might be more important for adopting scheduling than for irrigation technology.

Continuing with the description of structural aspects of the farms, the average size dedicated to vineyards is 36.1 ha, with a substantial range between the extreme values of 0.5 and 810 ha. In the model, we used size at three levels to estimate the impact of scaling from small to medium and large vineyards. Although the stratification is arbitrary, it allows for a better interpretation of the impact of size on the adoption of irrigation technology and scheduling. The stratification was done using three groups with the aim of classifying the sample as small, medium or large-scale producers, where the first group goes from 0.25 to 7.5 ha, the second from 7.5 to 33 ha, and the third from 33 to 810 ha. The stratification resulted from dividing the sample in three groups of an equal number of farmers. According to these size categories, in Table 3 we observe that as long as farmers continue to adopt, the average vineyard size increases. When farmers adopt irrigation technology and scheduling, 77.0 % of the farms fall into the last group (large farms), but when they do not adopt any of the technologies, the highest percentage of farms is concentrated in the first group (52.1 %), namely, small farms. The result is consistent with economies of scale of an investment. Several articles report the importance of size in the adoption irrigation technologies; hence, the trend observed here is expected (Schuck et al. 2005).

Table 3 Recursive Bivariate Probit (RBP) model results of scheduling and irrigation technology and the marginal effect at the mean

Variables	RBP model		Marginal Effects	
	Coefficient	<i>Std. error</i>	Coefficient	<i>Std. error</i>
SCH				
TECNI	1.6431***	0.3267	0.3115***	0.0618
EDUC	-0.0079	0.0226	-0.0014	0.0042
EXP	-0.0072	0.0064	-0.0013	0.0011
INT	0.5839**	0.2663	0.1107**	0.0497
ADV	0.3307*	0.1817	0.0627*	0.0334
OWN	0.2313	0.1837	0.0438	0.0345
SIZE2	0.0127	0.252	0.0024	0.0477
SIZE3	0.1645	0.2928	0.0311	0.0551
VALL2	-0.296	0.2216	-0.0561	0.0421
VALL3	-0.4208**	0.183	-0.0797**	0.0336
NET	0.0136**	0.0061	0.0025**	0.0011
Trust	0.1755*	0.0934	0.0332*	0.0176
Constant	-2.1735***	0.4239		
TECNI				
EDUC	0.0112	0.0222	0.0028	0.0055
EXP	-0.0135***	0.0051	-0.0034***	0.0012
INT	-0.1831	0.2021	-0.0462	0.0509
ADV	0.5910***	0.1446	0.1493***	0.0348
OWN	0.3796**	0.1541	0.0959**	0.0384
SIZE2	0.5145***	0.1874	0.1300***	0.0461
SIZE3	1.1075***	0.2091	0.2798***	0.0483
VALL2	0.3311	0.2171	0.0836	0.0541
VALL3	0.4177**	0.187	0.1055**	0.0465
SPILL	1.7092***	0.3115	0.4319***	0.0716
TRUST	-0.0968	0.0832	-0.0244	0.0209
Constant	-1.1670***	0.3603		
Log pseudolikelihood	-356.8776			
Rho (ρ)	-0.5651***	0.2074		
N	452			

Wald test of Rho = 0: $\chi^2(1) = 4.41232$ Prob $\chi^2 = 0.0357$

From the sample, it appears that only 37.6 % of farmers use a technical adviser, among which 46.4 % of this group have vineyards larger than 36 ha, making them rather large producers, but still leaving more than 50 % of this group among the medium to small farmers. Although it is expected that large farmers will have the financial means to afford an adviser, in contrast to medium to small farmers, the result can be explained by the assistance received by the last group from institutions that foster productive development, such as the Institute

for Agricultural Development (INDAP). Among the different level of adoption groups, it is clear that having an adviser has a strong relationship with the adoption of technologies. On the other hand, Table 2 shows that 73.6 % of the farmers who do adopt both technologies have an adviser, in contrast to only 22.6 % of the group that does not adopt either.

In the model, besides physical and human capital, we also considered variables representing social capital. As stated in the introduction, social capital has been acknowledged as an important factor in behavior and decision-making through the information flow provided by networks and trust (van Rijn et al. 2012; Eastwood et al. 2012; Bolino et al. 2002; Bouma et al. 2008; Lollo 2012; Bandiera and Rasul 2006).

We constructed two variables for networks, according the concept of network needed in each model. The first variable, which we called spillover, is defined by the percentage of farmers who use irrigation technology compared to the total number of farmers the producer knows. The second variable used as a measure of network is total number of acquaintances, which in this case reaches an average of 16.5 who have more farmer acquaintances who adopt irrigation and scheduling together. In the case of networks, while Table 3 shows mix results in terms of differences, in general no differences can be observed among groups, except for the farmers who only adopt scheduling, for whom networking is higher. The same trend is observed for spillover, as this group reaches 62.6 %, compared to 25.1 % of the lowest group (Table 2). Here the difference among groups is clear. The first group shows a higher spillover with respect to the other three groups, and for the third and last groups (respectively, adopters of scheduling but not irrigation and adopters of neither technology), spillover is statistically lower than for the others. For trust we use components extracted from a factor analysis using statements selected from the literature. (Appendix B presents the statements for each component and the factor analysis results).

3.2 Model Results

The model results reflect the descriptions shown in Table 3. The model performs well with a Log pseudo-likelihood equal to -356.87 and with six out of 12 significant coefficients in the *SCH* equation and seven out of 11 coefficients in the *IRR* equation. The most relevant result is that irrigation technology adoption is endogenous with adoption of scheduling. First, the marginal effect of irrigation technology adoption on adoption of scheduling is positive and highly significant, equal to 0.31, meaning that having irrigation technology increases the probability of adopting scheduling by 31 %. Second, the rho (ρ) coefficient that measures the correlation between the error terms between both equations is significant at the 99 % confidence level, with a value of -0.56. Although it seems contradictory that rho is negative, given that the coefficient of *IRR* on scheduling is positive, this is, in fact, expected. It implies that once *IRR* is included in the *SCH* equation and shows a positive impact on *SCH*, unobserved characteristics arise that make farmers more likely to increase scheduling and less likely to or “compelled” to introduce *IRR*. More simply, both technologies are complementary-positive sign of *IRR* on *SCH* equation-which explains the cases where we found that producers adopt both or none of the technologies; but this does not preclude finding other factors that show that both technologies could be substitutes, as in the cases where producers adopt only one of the technologies.

Besides the impact of adoption of irrigation technology on the use of scheduling, there are also other singularities that are interesting to note and which make each equation distinct in its predictions. First, in the *SCH* equation, the use of the Internet to get meteorological information is positive and significant, with a marginal effect of 0.11, although in the *IRR* equation, it is not significant. This result can be understood as showing that the use

of instruments for scheduling requires information. Therefore, as long as farmers use the Internet, they will probably be more open to the use of such instruments. On the other hand, to make the investment in irrigation technologies, farmers do not need to access meteorological information via the Internet, but information and human capital are required to use the technology. This result is also shown clearly in Table 2. Another difference between both equations is the impact of the adviser on the adoption of irrigation technology and scheduling. Although both equations show positive marginal effects on adoption, for irrigation technology the impact is significantly higher, revealing that having an adviser increases the probability of adoption by 15 %, while for scheduling the impact is less by half. The literature recognizes that the adviser is a key person in the decision making process at the farm level. According to Solano et al. (2003), family members and a technical adviser are the most common sources of information for decision making, and although in the case of problem detection family members are more relevant, for problem solving and seeking new technologies, the relevance switches to the adviser.

Regarding the size of the vineyard plantation, in contrast to how size is usually treated in the literature, we used a discrete stratified variable to identify the impact of this size on adoption. The results are interesting in two ways. First, it is evident that the impact on each group is different with regard to the adoption of irrigation technology compared to scheduling. While size is relevant for adoption of irrigation technology, which could be explained by the economies of scale of a large investment, scheduling is not a practice where economies of scale are present. In contrast, Frisvold and Deva (2012) found that farm size did have an impact on the adoption of scheduling; however, in our case, we are controlling the adoption of irrigation technology (*IRR*) in adoption of scheduling (*SCH*), which could explain the difference. We have already shown that *IRR* is endogenous with *SCH*, hence they could not be analyzed independently and doing so might generate bias in the results. Second, the impact of size on irrigation technology adoption reveals that when vineyards move from small to medium, the probability of adoption increases by 13 %, and by 28 % for vineyards that grow from medium to large, twice the impact. These results suggest that using a continuous variable for size which estimates a constant marginal effect hides the effect that size really has, and also emphasizes that investment in irrigation technologies presents economies of scale. In fact, the descriptive statics shown in Table 2 anticipated this result. Related studies that also reported a significant impact of size on irrigation technology adoption were already mentioned above.

Table 2 also shows that the educational level is relatively similar for farmers who adopt and do not adopt the technologies. A statistical difference, fewer years of schooling, is observed for the group that does not adopt irrigation technology or scheduling. On average, however, farmers reach high-school level. The model results show that educational level is not relevant, in contrast with most of the literature of technology adoption. However, (Jara-Rojas et al. [in press](#)) and Ramirez (2013) also reported that educational level is not significant for adopting scheduling and irrigation technology, respectively. An explanation for this phenomenon is that when the average farmer reaches a high level of education, education becomes less important in the explanation of adoption. Table 3 does not capture this conclusion since educational level could be controlled by social capital variables that have the same trend as educational level, as also shown in Table 2. Kaasa (2009) previously mentioned the positive relationship between human capital and social capital, represented by educational level. We could therefore expect that together in a model the estimated parameters will reflect the marginal effect of each individually. Experience is significant and

negative in the *IRR* equation, which is expected considering that farmers who are used to managing their crops in a certain way for a long time are more reluctant to change. In *SCH*, while experience is negative, it is not significant.

Turning now to the social capital variables, we can see that the variables representing trust and networks do have an impact on the adoption of both technologies. Networks were measured differently to encompass the appropriate concept of network for each technology, and in both equations the variables are significant. In the adoption of scheduling, networks have a positive marginal effect, in which knowing one additional colleague or neighbor increases the chance of adoption by 0.3 %. In the case of irrigation technology adoption, as the rate of producers who have implemented irrigation technology in relation to the total number of producers that the respondent farmer knows increases by one point, the impact on adoption is 43.19 %. Hence, in both cases, having stronger networks will increase the adoption of both technologies. This result has implications for extension programs, which should consider not only technical activities but also how to increase networks among farmers. (Jara-Rojas et al. [in press](#)) stated that extension did not have an effect on the adoption of scheduling, but training did. The results shown here could be understood as a reinforcement of those findings. Through training, producers can expand their networks and increase trust in information and the institutions providing the training; however, extension is just a one-by-one activity that does not allow for strengthening social capital factors. For confirmation, we can point to a successful case implemented by the Ministry of Agriculture of Chile in the '80s that had as an objective to increase performance in the agricultural sector by strengthening farmers' networks. The program consisted of forming groups of 10 to 12 farmers from the same geographical area who shared the same agricultural farming activities. The group had monthly meetings coordinated by a technical adviser, financed initially by the government and thereafter by the producers, which not only encouraged formation of networks but also trust. The program boosted the adoption of technologies and the subsequent yields in all crops.

Regarding trust, the results are different in both equations: while trust is significantly relevant for adopting scheduling, it is not for adopting irrigation technology. The explanation in this case is that adopting scheduling requires a learning process that implies trusting the information received from the community, institutions, or advisers; hence, trust is relevant. However, trust is not essential for implementing irrigation. As seen before in the case of irrigation technology adoption, one of the most important triggers was to have an adviser. In this sense, we argue that the concept of trust has been placed in the figure of the adviser.

The results of the study lead to rich lessons for future developments in promoting effective use of water resources. Knowing that governmental incentives to increase irrigated land have been successful in terms of irrigated area, it is also true that such incentives should be accompanied by programs that increase the adoption of scheduling. The percentage of farmers adopting scheduling instruments is rather low- just half of the percentage of farmers who adopt irrigation technology. Because increasing the adoption of irrigation also increases the probability of adopting scheduling, incentives should be in place for both. The adoption of scheduling is not triggered by size, which is a measure of capital, or by education and experience, which are factors that cannot be changed. The relevant factors here are soft skills, such as establishing strong networks, trust, and use of Internet, which can be improved by extension programs focusing resources on developing social and human capital.

4 Conclusions

The objective of this study was to estimate the use of irrigation technologies and scheduling as a joint recursive decision in which adoption of irrigation technologies results in scheduling. The study was conducted in the Central-South region of Chile on vineyard production systems. In the sample, almost half of the farmers have adopted irrigation technology, but only about a third have implemented scheduling. The results show the importance of adopting irrigation to promote the adoption of scheduling, but also that the adoption of scheduling requires human and social skills. This result has implications for decision makers. The investment in irrigation, which is subsidized at a high rate by the CNR, could be increased and complemented by investment in soft skills and educating farmers on the importance of scheduling and the use of irrigation systems. These results open questions for the government on how to improve the policy instruments they already have to increase water conservation. Networks, trust, using the Internet, and having an adviser appear to be relevant social capital factors that promote adoption of technologies. To design better instruments, more research is also needed, in particular more in-depth studies to characterize the behavior of adopters and non-adopters in relation to these specific factors, which could give more insight into how governmental institutions can design effective programs that promote a more efficient use of irrigation technologies and tools.

Appendix A: Description of trust variables

A factor analysis was performed to obtain the components of social capital. To elicit the components, we used a list of statements that the farmers rated according to a Likert scale from 1 to 5. Five components were elicited as listed below:

- Component 1: Networks
- Component 2: Trust in Institutions
- Component 3: Trust in Water Communities
- Component 4: Trust in General
- Component 5: Norms

In the model we use the component Trust in General since it covers a wider range of statements that, according to Solano et al. 2003; Eastwood et al. 2012, are more relevant in determining adoption. Table A.1 present the results for this specific component.

Table 4 Factor analysis results of the component Trust in General (Cronbch's Alpha: 0.762)

Statement	Mean	Standard deviation	Loading rotating	
			PM(1)	SM(2)
I can trust in people around me without the need to be very cautious.	3.630	1.120	0.441	0.508
Farmers are reliable people.	3.920	1.030	0.497	0.508
I consider that other farmers will not harm me for their own benefit.	3.080	1.280	0.493	0.478
I spend time with my friends because I think it is important to share time with them.	4.030	1.150	0.440	0.400

Appendix B: Geographical characterization of the Cachapoal-Colchagua, Curicó and Maule valleys

Table 5 Geographical characterization of the Cachapoal-Colchagua, Curicó and Maule valleys

Valley	Surveyed producers	Characteristics
Cachapoal - Colchagua	164	Both valleys are located in the O'Higgins region of Chile and are characterized by their sub-humid, Mediterranean temperate climate, ideal for the production of red varieties. The hours of light, high thermal oscillation, and the existence of various microclimates allow for growing different wine strains. This region has a pronounced seasonality, where winter concentrates the most of annual rainfall. It has an average temperature of 22 °C and precipitation around 600 mm. The soils are alluvial in origin. These valleys are located north of the Curicó and Maule valleys.
Curicó	97	Located in the Maule region of Chile. Curicó valley is considered the center of the Chilean wine growing because of its high concentration of vineyards. It has a temperate Mediterranean climate with a dry period five months a year, precipitation around 700 mm, and an average temperature of 20 °C. White varieties are best grown in coolest areas of the valley. It has numerous water sources and the soil is alluvial and volcanic in origin.
Maule	191	Located in the Maule region of Chile south of Curicó valley and considered the "Cradle of Chilean wine" because of its origin during the time of Spanish colonization. It has a temperate Mediterranean climate with rainy winters. The soils are acids and clayed, which partially reduces productivity to benefit the quality of the grapes. It has many rivers that also exert influence on the quality of their wines.
Total	452	

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