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Trading Under Risk and Uncertainty in an Agricultural Water Market in Chile

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Risk and uncertainty in a water market will generate trading patterns that differ from those expected under conditions of perfect foresight. Although trades will occur based on differences in VMPs of water in both markets, they will also be generated by differences in risk. Some farmers will choose to reduce relative risk by purchasing additional water rights whereas other farmers will hold fewer rights and rely on the spot market to meet their needs. Since spot markets are riskier than permanent rights markets, farmers who are better able to bear risk are more likely to participate in the spot market than those who are not. Farmers who face less risk will be sellers in both markets whereas farmers who face more risk will be buyers. In the polar case of perennial crop producers, they will not participate in spot markets and will tend to be only buyers in permanent rights markets in an attempt to insure againt potential losses in future capital productivity of their stock of perennial crops.

50 Word Abstract

Risk and uncertainty in a water market generate trading patterns different from those expected under perfect foresight. Using data on leasing and permanent rights transactions collected from farmer surveys in Chile's Limarí river basin, hypotheses regarding water market participation and the effect of risk on those decisions are tested.

ABSTRACT
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Risk and uncertainty in a water market will generate trading patterns that differ from those expected under conditions of perfect foresight. Although trades will occur based on differences in VMPs of water in both markets, they will also be generated by differences in risk. Some farmers will choose to reduce relative risk by purchasing additional water rights whereas other farmers will hold fewer rights and rely on the spot market to meet their needs. Since spot markets are riskier than permanent rights markets, farmers who are better able to bear risk are more likely to participate in the spot market than those who are not. Farmers who face less risk will be sellers in both markets whereas farmers who face more risk will be buyers. Perennial crop producers with high VMPs of water and who face the highest risk from water deficits, will not participate in spot markets and will tend to be only buyers in permanent rights markets in an attempt to insure against potential losses in the future productivity of their capital stock of perennial crops.

Using data on short-term leasing and permanent rights transactions collected from over 300 farmer surveys during the 1996/97 growing season, water market participation decisions for spot and permanent rights markets are modeled in a discrete choice framework Results support the hypothesis that risk has a significant effect on which market a farmer will participate in and in whether they will demanders or suppliers of water or water rights.

Trading Under Risk and Uncertainty in an Agricultural Water Market in Chile

The past decade has witnessed an increased interest in private markets as a vehicle to allocate water resources. Such markets are hypothesized to improve water efficiency by moving resources to their highest-valued uses either through permanent rights or short-term volumes trade. In an agricultural setting we would expect to observe trades to the extent that the value of the marginal product (VMP) of water differs among farmers. This may prove an insufficient measure, however, given uncertainty surrounding future water supply and the existence of heterogeneous risk among farmers. Incorporation of risk and uncertainty in the valuation of water rights and water volumes will generate trading patterns different from those expected when only the VMP of water is taken into account.

Water is stochastic. Inter- and intra-seasonal variability can be quite high. To protect against downside uncertainty some farmers hold additional rights to ensure a minimum supply of water in dry years whereas others choose to hold fewer rights, relying on the spot market to meet their needs in dry years. Although differences in the VMP of water can explain some water market activity, prediction of which farmers will be in each market will depend largely on the amount of risk that each is willing and able to bear.

This paper will test hypotheses regarding water market participation by empirically examining a largely unregulated spot and permanent rights water market currently active in Chile's Limarí river basin. Using data on short-term leasing and permanent rights transactions, collected from over 300 individual farmer surveys during the 1996/97 growing season, this research will illuminate the determinants of short-term trading versus permanent rights trading and the effect of risk on those decisions.

Conceptual Model

Farmers will make both short-term decisions regarding current production and spot market trades, and long-term decision regarding future production and permanent rights trades by maximizing the present discounted value of the expected utility of profit over a finite time horizon. Output prices and spot market lease prices are random variables with known probability distributions, and farmers are assumed to be risk averse. The individual farmer's maximization problem, therefore, can be represented as:

$$\max_{\alpha} V_i(\pi_{it}) = \sum_{\tau=1}^{T} \beta_t EU_i(\pi_{it}) + \beta_{T+1} U_i(\pi_{iT+1}) \qquad \textbf{(1)}$$

where $\tilde{\pi}_{it}$ is stochastic profit of farmer *i* at time *t* and π_{iT+1} is the final value of the total stock of water rights of farmer *i* at the end of the planning period.

Each farmer will maximize (1) subject to resource constraints on land and water. Assuming for simplicity that land is fixed, the land constraint for farmer *i* is:

$$\bar{L}_{it} = LI_{it} + F_{it} \qquad (\delta_{it}) \qquad \textbf{(2)}$$

where $(\bar{L})$ is the total land endowment, (F) is land fallowed, (LI) is land allocated to irrigated production and δ represents the shadow price of land. The water constraint represents the total amount of water available each growing season. Since water is a stochastic resource, farmers will base their decisions on expected water supply. The water constraint for farmer *i* is:

$$E(\tilde{W}_{it}) \geq WI_{it} + WL_{it} - WR_{it} \quad (\gamma_{it}) \qquad \textbf{(3)}$$

where $(\tilde{W})$ is the total stochastic volume of water available to farmer *i*, (WI) is water used in irrigation, (WL) is water leased out, (WR) is water rented in and γ is the on-farm shadow price of water.

Maximization of (1) is also subject to a state equation representing the change in the stock of water rights of farmer *i* over time:

$$A_{it} \equiv A_{it-1} + AB_{it} - AS_{it} \quad (\lambda_{it}) \qquad \textbf{(4)}$$

Total water rights held by the farmer in the current period must be exactly equal to water rights held in the previous period (A_{t-1}) plus net purchases of water rights in the current period ($AB_t - AS_t$). The multiplier on this difference equation, λ, represents the marginal present discounted value of the farmer's stock of water rights.

Finally, for those farmers producing perennial crops there is an additional state equation representing the change in the stock of perennial crops over time:

$$K_t^P = \eta K_{t-1}^P - R_t + Pl_t \qquad \textbf{(5)}$$

where K_t^P is the stock of perennial crops at time *t*, R_t are plants removed from the stock at time *t* and Pl_t are new plantings at time *t*. The coefficient η reflects the change in the productivity of the capital stock as the plants age.

Optimization of the dynamic program yields first-order equilibrium conditions from which reservation lease and permanent rights prices can be derived. These reservation prices illustrate the three sources of risk faced by farmers when making water supply decisions: spot market lease price risk, water supply shortfall risk; and for those farmers who produce perennial crops, capital stock productivity risk. Each risk has an associated uncertainty cost that will vary among farmers.

Risk and Uncertainty in the Spot Market

Spot markets are risky, but the risk is different for farmers who rent in water volumes as opposed to those who lease out. Expected reservation lease prices for renters and lessors derived from the first order conditions are:

$$\overline{P}_{renter}^{L} \approx e_i \left[\overline{P}_{sct} \frac{\partial f_{sct}(\cdot)}{\partial e_i WI} \right] - \frac{1}{2} \overline{R} \left[\frac{\partial \sigma_\pi^2}{\partial e_i WI} e_i + \frac{\partial \sigma_\pi^2}{\partial WR} \right] \qquad \textbf{(6)}$$

$$\overline{P}_{lessor}^{L} \approx e_i \left[\overline{P}_{sct} \frac{\partial f_{sct}(\cdot)}{\partial e_i WI} \right] - \frac{1}{2} \overline{R} \left[\frac{\partial \sigma_\pi^2}{\partial e_i WI} e_i - \frac{\partial \sigma_\pi^2}{\partial WL} \right] \quad \textbf{(7)}$$

where $\overline{R}$ is the Arrow-Pratt coefficient of absolute risk aversion and σ_π^2 is the variance of profit. The first term in the expected lease price is the expected VMP of water adjusted for irrigation efficiency, e_i. The second terms are the associated costs of uncertainty for renters and lessors. Assuming equal risk aversion, these costs are higher for renters because only they face the downside uncertainty of water supply shortfall. Indeed, lessors receive a risk deduction benefit from spot market participation since they only participate when prices are sufficiently high to induce them to remove land from irrigation. Correspondingly, renters must be compensated for the extra risk they bear on the spot market through lower lease prices. Since the reservation lease price of the lessor will always be higher than that of the renter for equal irrigation efficiencies and VMPs of water, trade will only occur between farmers who differ in irrigation efficiency, VMP of water or risk.

Risk and Uncertainty in the Permanent Rights Market

Permanent rights markets as a source of water supply are less risky than spot markets since farmers face only the uncertainty of future water supply rather than the combined uncertainty of water supply and lease prices. Not only can the purchase of additional rights insure a farmer against shortages in dry years, but it can provide a form of income insurance as well if the farmer's water demand is elastic enough to substitute water leasing for irrigated production in dry years.

The permanent rights reservation price derived from the first order conditions is:

$$P_t^A \approx \sum_{\tau=1}^{T} \beta_t \left[\overline{P}_t \frac{\partial f(\cdot)}{\partial e_i WI} e_i - c^w - \frac{1}{2} \overline{R} \frac{\partial \sigma_\pi^2}{\partial e_i WI} e_i \right] \quad \textbf{(8)}$$

where the first term represents the present discounted value of benefits from irrigation as measured by the expected VMP of water and the second term represents the marginal risk deduction associated with uncertainty surrounding future water supply. Farmers will value water rights more

highly the higher their value of the marginal product of water in irrigation, the higher their irrigation efficiency and the lower the risk they face from future shortages in water supply. Like renters in the spot market, permanent rights holders must be compensated for the risk they bear in the stochastic future flow of the water right through lower water rights prices. Therefore, we would expect to see trades of permanent rights from farmers with less reliable water supplies to farmers with more reliable supplies or from farmers with lower irrigation efficiency and/or VMP of water to farmers with higher irrigation efficiency and /or VMP of water.

Additional Risk: The Special Case of Perennial Crop Producers

Perennial crop producers are unique among farmers in a water market because they face the additional risk of future productivity loss of their stock of perennial crops from a water supply shortfall. This risk is incorporated into the present discounted value of the stock of perennial crops derived from the first order conditions:

$$\rho_{it} = \sum_{\tau=1}^{T} \beta_t U'(\overline{\pi}) \left[\eta^{t-1} \overline{P}_{pt} \frac{\partial f(\cdot)}{\partial K^p} - \frac{1}{2} \overline{R} \frac{\partial \sigma_\pi^2}{\partial K^p} \right] + \eta^{T-1} \rho_T \qquad \textbf{(9)}$$

where the first term represents the present discounted value of the capital stock of perennial crops, adjusted for decreases in productivity as the stock ages, and the second term represents the uncertainty cost associated with the potential lost future productivity of the stock from decreased water supply. The existence of this added uncertainty increases the risk perennial crop producers must bear, relative to other farmers, from water supply shortfalls.

Empirical Model and Results

Data for the model of water market participation is taken from surveys, carried out in 1997, of 316 farmers in the Limarí river basin of Northern Chile. The survey covers production for the 1995/96 and 1996/97 growing seasons and collects water market participation information on spot market trades for the 1995/96 and 1996/97 seasons and permanent rights trades since the inception of the water market in 1981.

The decision to participate in the water market and subsequent decisions on the form of participation is modeled in a discrete choice framework as a univariate probit model. Four separate equations were estimated for the decisions to (1) participate in the spot market, (2) rent or lease water given participation in the spot market, (3) participate in the permanent rights market, and (4) buy or sell water rights given participation in the permanent rights market.

Spot Market Participation

Table 1 presents the results of the probit regression of spot market participation based on whether the farmer had perennial crops (DPERM), the percentage of land planted to perennial crops (PERCPERM), scale of operation as measured by whether the farmer operated as a family farm (DFAMFARM) or had farms in more than one sector of the river basin (MULTSEC), availability of off-farm income based on whether the farmer derived the majority of his income from agriculture (DAG) or from some other source, participation in the permanent rights market (PARPERM) and years of experience farming in the Limari river basin (YRS). Also to test for thickness in the spot market, a variable measuring the percent of arable land fallowed (FALLOWH) as an indicator of participation in the spot market was added. Given a thick spot market, we would not expect farmers to fallow a significant percentage of their land without selling their water on the spot market to other farmers.

Table 1: Probit Model: Spot Water Market Participation
Limari River Basin, 1996/97 Growing Season

Explanatory Variable	*Coefficient*	*Wald-Statistic*	*Significance Level*	*Variable Means*
DAG	0.5140	5.009	0.0252	0.7475
DFAMFARM	-0.6275	8.026	0.0046	0.7929
DPERM	-0.7421	5.789	0.0161	0.5454
FALLOWH	0.5550	3.084	0.0790	0.4805
MULTSEC	0.9013	4.414	0.0356	0.0606
PARPERM	-0.3190	2.196	0.1384	0.3232
PERCPERM	0.7710	2.280	0.1310	0.2634
YRS	-0.1142	2.789	0.0949	27.3737

Model Chi-Square = 21.15 with 7 d.f.
Number of Observations=198
Overall Prediction Rate: 69.69%

As can be seen by the negative and significant coefficient on DPERM, permanent crop producers are less likely to participate in the spot market than annual crop and grain producers, although the percentage of land planted to permanent crops does not have a significant influence on spot market participation. This result is consistent with the hypotheses relating to the role of the VMP of water and risk in spot market participation. Perennial crops tend to be higher value crops with correspondingly higher VMPs of water. Perennial crop producers also tend to have higher irrigation efficiencies than annual crop producers. The effect of these characteristics is to price perennial crop producers out of the spot market as lessors. We are also unlikely to see perennial crop producers renting in water in the spot market. Since these producers face the additional risk of the loss of the future stream of benefits from their capital stock of plants in the event of a water shortfall, they will tend to demand relatively more rights and relatively less spot volumes as a means of insuring themselves against loss and in an attempt to reduce their overall risk relative to other producers by not facing the risk associated with stochastic lease prices.

The greater the percentage of land fallowed by a farmer, the more likely they are to have participated in the spot market, supporting the hypothesis of a thick spot market. Farmers with little off-farm income are more likely to participate in the spot market than those with significant off-farm

income. These farmers are likely to face a higher income risk associated with irrigated production and therefore a more inelastic demand for water.

Farmers who have family-run farms are less likely to participate in the spot market than more commercialized farmers whereas farmers who have farms in more than one sector are more likely to participate. This result suggests that scale of operation is an important determinant of spot market participation with medium- to large-scale farmers participating more than smaller farmers. Assuming decreasing absolute risk aversion, this result is consistent with the hypothesis that farmers who participate in the spot market are better able or willing to bear risk than those who do not.

Renting Vs. Leasing Given Spot Market Participation

Table 2 presents the results of the probit regression of renting in vs. leasing out water based on farmer's storage capacity per hectare of arable land (CAPHA), the absence of substantial off-farm income (DAG), scale of operation based on whether the farmer could be classified as a small enterprise farm (DPEQEMP) or had farms in more than one sector (MULTSEC), whether the farmer had participated in the permanent rights market (PARPERM) and the percent of arable land fallowed (FALLOWH).

Table 2: Probit Model: Renting In vs. Leasing Out in Spot Market Limari River Basin, 1996/97 Growing Season

Explanatory Variable	*Coefficient*	*Wald-Statistic*	*Significance Level*	*Variable Means*
CAPHA	0.1274	3.294	0.0696	201.2561
DAG	0.7791	5.448	0.0196	0.7879
FALLOWH	-1.0216	6.452	0.0111	0.5318
DPEQEMP	-0.6827	2.226	0.1358	0.2273
PARPERM	-0.8390	4.326	0.0376	0.2879
MULTSEC	0.0866	0.033	0.8544	0.1212

Model Chi-Square = 19.21 with 5 d.f.
Number of Observations=66
Overall Prediction Rate: 71.2%

The more land that a farmer has fallowed the more likely they are to be a lessor in the spot market. This supports the hypothesis that farmers will pull land out of production to lease water in dry years.

Farmers with greater storage capacity per hectare of arable land are more likely to be renters in the spot market than lessors. Increased storage capacity translates into improved irrigation efficiency, consistent with the hypothesis that trades will occur from farmers with lower efficiencies to farmers with higher efficiencies.

Farmers with little or no off-farm income are more likely to be renters than lessors. Like participation in the spot market, this variable may measure the elasticity of water demand of a particular farmer. Lessors will tend to be farmers who have an elastic enough demand for water to be able to pull land out of production to lease water in dry years when lease prices are high.

Small enterprise farmers are more likely to be lessors in the water market than family farmers or larger more commercialized farms. Small enterprise farmers are defined as those farmers who employ non-family labor on a consistent and regular basis but which are not incorporated. As family farms tend not to participate in the spot market, the significance of small enterprise farmers in leasing may imply that most renters are medium- to large-scale farmers, consistent with the hypothesis that renters will be those farmers better able to bear the risk of stochastic lease prices. Using this logic, we would also expect farmers with farms in more than one sector to be more likely to rent in the spot market as this may be highly correlated with scale of operation. This variable was insignificant, however, in explaining the decision to rent in or lease out although it is not the only indicator of scale of operation.

The Permanent Rights Market

Table 3 presents the results of the probit regression of permanent water rights market participation as a function of location above or below the reservoir (ABRES), farm size (CULTHA), whether the farmer cultivates export grapes (DEXPORT), scale of operation as measured by whether the farm is family-run (DFAMFARM) or if the farmer has farms in more than one sector (MULTSEC), whether the farmer participated in the spot market in the 1996/97 growing season

(PARSPOT) and irrigation technology as measured by the existence of on-farm reservoirs (RES) or non-traditional irrigation systems. (TECRIEGO)

Table 3: Probit Model: Permanent Rights Market Participation
Limari River Basin, 1981-1996

Explanatory Variable	*Coefficient*	*Wald-Statistic*	*Significance Level*	*Variable Means*
ABRES	0.5772	10.5170	0.0012	0.6548
CULTHA	0.0003	0.0595	0.8070	23.9276
DEXPORT	0.5859	6.5324	0.0097	0.1710
DFAMFARM	-0.9763	48.6227	0.0000	0.8193
MULTSEC	0.8285	4.5839	0.0323	0.0484
PARSPOT	-0.2854	1.8387	0.1751	0.2258
RES	-0.6583	11.7511	0.0006	0.3903
TECRIEGO	-0.0662	0.0980	0.7539	0.2710

Model Chi-Square = 35.56 with 7 d.f.
Number of Observations=310
Overall Prediction Rate: 74.19%

Farmers located above the reservoir system are more likely to have bought or sold water rights than those located below the reservoir system. This is expected given that the potential trading area for water rights is larger below the reservoir system. Farmers with farms in more than one sector are more likely to have participated in the permanent rights market, whereas family farmers are less likely to have participated. This suggests, once again, that scale of operation is an important determinant of water market participation, although the impact of farm size, as measured by the coefficient on CULTHA is not a significant determinant of permanent rights market participation.

Farmers who grow export grapes are more likely to have participated in the permanent rights market than farmers who grow other permanent or annual crops consistent with the hypothesis that perennial crop producers facing high risk of capital productivity loss will demand more rights than spot volumes.

Farmers with on-farm reservoirs are more likely to have participated in the permanent rights markets than farmers without reservoirs. This may reflect the influence of irrigation technology on permanent rights market participation as farmers with reservoirs are able to reduce the variability of

on-farm water supply and thus the associated costs of stochastic flows. The existence of a non-traditional irrigation system on farms, however, did not impact the participation decision in the permanent rights market, although we may expect it to influence the decision to buy or sell rights.

Participation in the spot market during the 1996/97 growing season was not indicative of participation in the permanent water rights market in past years, suggesting that participation in one market has no influence on participation in the other.

Buying vs. Selling Given Permanent Rights Market Participation

Table 4 presents the results of the probit regression of the decision to buy vs. sell water rights as a function of farm size (CULTHA), scale of operation (DFAMFARM, MULTSEC), irrigation technology (RES, TECRIEGO) and years of experience farming in the Limari river basin.

Table 4: Probit Model: Buy vs. Sell Rights Decision
Limari River Basin, 1981-1997

Explanatory Variable	*Coefficient*	*Wald-Statistic*	*Significance Level*	*Variable Means*
CULTHA	0.012	0.9409	0.3322	31.376
DFAMFARM	-1.460	9.096	0.0026	0.722
MULTSEC	-2.953	6.411	0.0113	0.101
RES	1.613	8.892	0.0029	0.367
TECRIEGO	1.981	13.155	0.0003	0.316
YRS	-0.019	2.532	0.1160	29.823

Model Chi-Square = 63.36 with 5 d.f.
Number of Observations=79
Overall Prediction Rate: 89.87%

The factors most significant in influencing the decision to buy water rights are the existence of on-farm reservoirs and non-traditional irrigation systems. Both types of on-farm water infrastructure increase irrigation efficiency and reduce the risk costs associated with stochastic water flows, thereby increasing the value of water rights to the individual farmer.

Family farmers are more likely to sell water rights. Many small farmers are liquidity-constrained and often have sold rights to pay off large debts, explaining the negative coefficient on this variable. Land in the Limari river basin is of little value without water, so we would not

expect to observe farmers selling water rights unless they were exiting agriculture or facing a liquidity constraint. The large capital investment necessary to purchase water rights also indicates that buyers in the permanent rights market may tend to be medium to large size farmers or farmers with larger scales of operation. The coefficient on MULTSEC, however, suggests that farmers with farms in more than one sector are more likely to sell water rights which is counterintuitive to our hypothesis. This may simply be an aberrant finding given that only 9 of the 80 farmers in the permanent rights market had farms in more than one sector.

Conclusion

Risk and uncertainty in a water market will generate trading patterns that differ from those expected under conditions of perfect foresight. Some farmers will chose to reduce relative risk by purchasing additional water rights whereas other farmers will hold fewer rights and rely on the spot market to meet their needs in dry years. Since spot markets are riskier than permanent rights markets, farmers who are better able to bear risk are more likely to participate in the spot market than those who are not.

Although trades will occur based on differences in VMPs of water in both markets, they will also be generated by differences in irrigation efficiency and risk. Farmers who face less risk will be sellers in both markets whereas farmers who face more risk will tend to be buyers. In the polar case of perennial crop producers, they will not participate in spot markets and tend to be only buyers in permanent rights markets in an attempt to insure against potential losses in future capital stock productivity from water supply shortfalls.