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Experimental evidence on the relative efficiency of forward contracting and tradable entitlements in water markets

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ABSTRACT

This paper experimentally tests if adding forward trading or tradable entitlements to already commonly used spot trade in water markets improves allocation and production efficiency. We find that forward contracts significantly increase efficiency, while tradable entitlements do not. The advantage of forward contracts increases further after a climate change shock, which reduces the expected total water supply. However, tradable water entitlements are rather more damaging than beneficial. Due to the complexity involved in pricing entitlements they not only fail to increase efficiency, but are often seriously mispriced, which results in concentrated holdings and considerable wealth inequality across market participants.

Keywords: climate change shock; entitlements; experiment; forward contracts; water markets.

1. INTRODUCTION

Increasing future water scarcity as a consequence of climate change or competition among user groups is recognized as a global risk (World Economic Forum, 2015). Recognition of this risk has led regional governments in countries such as the United States, Spain, Mexico, Chile and Australia to develop and adopt water markets (Grafton, Libecap, McGlennon, Landry and O'Brien, 2011) that: facilitate reallocation of scarce resources across competing demands (Matthews, 2004), reduce agricultural sector risk and uncertainty in production decisions (Calatrava and Garrido, 2005), and minimize productive disruptions during periods of drought (Wittwer and Griffith, 2011). There are some specific properties of the commodity of water and its use in agriculture which have to be taken into account when trading institutions are designed. The three most important are as follows. First the total supply of water varies across time and is not known ex ante. Second, property rights are not naturally assigned. And finally, production decisions (i.e. sowing and decisions on livestock) have to be taken before the total supply for the relevant period is known. These properties imply that an efficient trading system a) assigns property rights conditional on current supply, b) allocates the available water efficiently within a production period, once production decisions have been taken and c) induces efficient production decisions given the uncertainty of water supply. A commonly used market instrument is tradable water allocations. Depending on the total supply of water within a season water is initially allocated according to some entitlement[1], and can then be traded on a *spot market*. Theoretically, such a setup is sufficient to achieve efficiency if some assumptions hold. If the spot market works efficiently and market power is absent, then annual water supplies will be allocated efficiently conditional on the production decisions taken. Thus, if market participants have enough information and hold rational expectations such that they can properly predict water prices for all possible total supply scenarios, they can make efficient production decisions.

If for some reason producers face uncertainty about the ensuing prices for different future rainfall scenarios then additional market institutions have the potential to improve efficiency (Gaydon, Mienke, Rodriguez and McGrath, 2012). The two most appealing mechanisms are: tradeable entitlements akin to permanent property rights, and derivatives such as forward contracts or options. A crop farmer might only want to commit to production (i.e. plant or sow) if she has secured enough future water for irrigation. If entitlements are tradeable (*licenses trade*), then producers who are highly water dependent can mitigate their risk of not being able to secure enough water in the spot market by purchasing additional entitlements ahead of production decisions. Similarly, derivative products (*forward contracts*) enable participants to insure

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[1] In this case, a water entitlement represents a correlative or mutual relationship right where holders own a share of the total available consumptive pool. This is different to absolute rights, such as those based on seniority, which are based on volume and priority.

themselves against unfavourable future spot-price movements (Wolak, 2000).[2] While it is possible to theoretically evaluate different water market institutions, the results depend on the assumptions made. For an evaluation of the impact of *license trading* and *forward markets*, assumptions regarding rationality and expectation formation by the market participants are particularly important. It is a priori unclear to which extent, and how, deviations from full rationality and rational expectations may influence efficiency under different market institutions. Moreover, given the number of market participants and the complexity of water markets, it is unlikely that all participants always exhibit rational expectations and obey full rationality. This paper therefore uses experimental techniques to evaluate the welfare implications when *tradeable licenses* or *forward contracts* are added to a standard *spot market*.

Our experimental environment captures the most salient elements of agriculture. Farmers live for multiple periods, and survival is stochastic. Production decisions have to be taken before the total supply of water is known. A heterogeneity of production technologies models different crops and different farm sizes and allows for gains from water trade. Finally, we introduce a climate-change shock that reduces the expected amount of water, in order to be able to judge which trading institution best deals with such shocks. Note, however, that our setup is generic. It does not try to closely mimic conditions in any specific region. Instead we are looking for general behavioural regularities. For that reason all results are of a qualitative nature only. The dynamic feature of our environment is crucial for investigating license trade in particular. To our knowledge this paper is the first experimental paper with long-lived farmers who bring forward their tradable water entitlements and bank balances from period to period, and who earn or have to pay interest. This allows us to look at the important long-term implications of license trade. The consequences

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[2] Following significant legislative evaluation and change forward contracts are being slowly introduced to Australian water markets (Waterfind, 2014).

of water markets and license trading for the long-term efficiency of production and the wealth distribution in the industry can only be assessed in a dynamic experiment.

Besides the obvious policy relevance of our work we also make a methodological contribution. Our setup can be used for other questions where long-term impact of markets, policies or individual decisions is of interest. The underlying model has two main advantages over other models when implementation in the laboratory is a concern. First of all, the equilibrium predictions are time-invariant. For example, dynamic models with finite periods would have declining equilibrium license prices, which make it hard to compare behaviour over periods, and are also known to cause bubbles in asset experiments (Noussair and Tucker, 2006). The time-invariance in our model does not only require a stochastic stopping rule but also the modelling trick of including bequests in the farmer's objective function. To our knowledge we are the first to propose such an environment. Secondly, our setup does not require an induced discount rate. Induced discount rates are problematic, as they reduce the money at stake – and therefore the incentives to try hard – for participants in later rounds (Harrison, Lau and Rutström, 2010). We find that adding forward contracts to the spot market significantly increases efficiency, while added license trade does not improve efficiency compared to spot markets alone. If they have an impact at all, then tradable water entitlements are rather more damaging than beneficial. Due to the complexity involved in pricing entitlements, valuations differ largely across market participants which leads to concentration of the entitlements through trade. This both leads to inefficient production decisions and to large wealth inequality. The latter is further exacerbated, since the market is not able to remove mispricing. Further, our finding that forward contracts are a very useful measure to improve efficiency even in an environment where under full rationality spot markets alone could do the job, is highly robust to system shocks. Under forward contracts the adjustment after the climate-change shock works best.

2. RELATED LITERATURE

The most common forms of water market trade involve simple (spot) transfers of temporary water allocations. In some countries more risk-averse farmers are motivated to buy water entitlements from less risk-averse farmers to insure themselves against supply shocks , where in other places complex water right transfer products are evolving to manage water supply-scarcity risk (Cristi, 2007). Complex water trade derivatives may enable farmers to increase earnings and generate additional water transfers at the margin, relative to traditional (spot-market) water transfers (Hansen, Howitt and Williams, 2008). Derivative products include option (futures) and forward contracts that require a buyer to purchase water-rights from a seller at an execution date for a previously agreed price. There is a subtle difference between the two derivative types: once entered into, forward contracts must be fulfilled; whereas with option contracts the buyer (seller) is allowed to forgo the water purchase (sale) before the contract expiration date but the option deposit will forfeit to the seller (buyer) (Hadjigeorgalis, 2009). Ignoring the potential benefits from derivative water trade may place additional and significant future imposts on the public purse (Leroux and Crase, 2010). Thus a fuller understanding of water market efficiency outcomes could facilitate improved trading institutions that allow participants to better coordinate their decision making (Suter, Spraggon and Poe, 2013).

Experimental examination of forward contracting features extensively in tradeable emission permit markets, where such products can: assist in the management of strategic behaviour (arbitrage) (Allaz and Vila, 1993); improve market cost efficiencies from increased trade volumes and dynamic efficiencies associated with cross-period uncertainty (Godby, Mestelman, Muller and Welland, 1997, Muller and Mestelman, 1994); reduce supply shock impacts and help to avoid increased spot market prices (Wolak, 2003); provide design and implementation advantages over existing trade products and help to manage uncertainty between periods (Maeda, 2004); and dilute market power among oligopolistic energy providers (Brandts, Pezanis-Christou and Schram, 2008). Water managers may be similarly interested in strategic behaviour or supply-shock market impacts, but water market structures are not typically oligopolistic in nature. Further, assessments of efficiency improvements from license trade and forward contracting is less common in water market settings, possibly reflecting the relative immaturity of water markets in many instances especially with regard to information collection and dissemination among water users (e.g. farmers). Insights can arise from better understanding the design details of license trading schemes, such as in pollution permits (Montgomery, 1972). While there are numerous examples in pollution and electricity market settings of share and coupon comparisons (e.g. Muller and Mestelman, 1994) and studies concerning the ability to bank or borrow permits (e.g. Maeda, 2004), there are fewer studies providing insight into the initial allocation arrangements for permits/shares beyond auction arrangements—especially in the water literature where property rights are typically ‘grandfathered’ according to historic or pre-determined systems. Given the high prevalence of spot market activity with high variability in most water markets we are also keen to test for price-stabilization benefits from incorporating license and forward contract trade.

The seminal work on commodity-price stabilization by Newbery and Stiglitz sparked two competing theoretical literature strands on the effects of forward contract use by firms competing over quantity (Schubert, 2013). The first strand (Le Coq and Orzen, 2006) argues that forward contracts increase competition and market efficiency by improving the spot market position of some firms relative to others when they sell some quantity of product forward. The second strand challenges the market efficiency increasing prediction arguing that forward markets can only drive efficiency under finite horizon assumptions. When this assumption is relaxed, for example in the case of infinitely repeated oligopoly settings as found by Liski and Montero (2006), forward contracts result in tacit firm collusion or strategic behaviour, particularly where such action may increase market power (Murphy and Smeers, 2010). Importantly the range of discount factors that support the collusive equilibrium is wider under repeated firm interaction in both forward and spot markets (Schubert, 2013). The theoretical disparity surrounding efficiency improvements between spot and forward contract markets in the context of future uncertainty justifies additional research in the area. In water markets where market power may be of less concern dependent upon the number of participants and heterogeneity of water uses, and where periodic shock impacts to both supply and demand spot prices may be mitigated by derivatives, valuable insights can be gained by experiments in water trade product design and implementation—especially with regard to increased water market efficiency.

Using real world data for such an analysis is difficult. First of all we do not know of any natural experiment which would allow for a causal examination of the impact of forward contracts to water. Moreover, the lack of information on individual production functions and expected product prices makes it hard to separate between different pricing determinants such as technology, expectations, or bounded rationality. There are also policy benefits to evaluating water market mechanisms through experimental economic approaches prior to implementing institutional and/or design changes (Suter, Duke, Messer and Michael, 2012) particularly where insufficient data for conventional econometric analysis is available (Hansen, Howitt and Williams, 2008).

Previous experimental approaches to estimating allocative efficiency gains from the trade of water products provide a great deal of insight. For example Connor et al. (2008) used an experimental setting to test the significance of impediments to a proposed dryland cap and trade water salinity credit system. Other experimental economic analysis has focused on the effects of regulatory restrictions (Garrido, 2007); the presence of significant environmental agency trade (Tisdell, 2010); and the advantages of double-auction structures for water allocation markets (Tisdell, 2011). Further, Hansen et al. (2008) used an experimental setting to include option contracts between competitive/monopsony water agents and smaller water users in California to manage dry-year supply risk. Finally, Lefebvre et al. (2012) innovatively combine both water license and spot markets in experimental settings to estimate the impact of transaction costs and supply reliability levels on trade behaviour, without investigating derivative water trade arrangements specifically. The main contribution of our paper is such a specific investigation. We therefore addresses the following two research questions: a) does the introduction of tradable licenses and forward contracting increase efficiency compared to having only a spot market; and b) does the presence of a climate (i.e. supply variability) shock impact upon the efficiency of trade across the spectrum of water market products? Contrary to Lefebvre et al. (2012) these questions are considered in the context of dynamic short-term (i.e. intra-seasonal) water management decision making, which have long-term impacts through the license holdings and balance sheets of farmers.

3. THEORETICAL ENVIRONMENT

The objective of the experiment is to create a dynamic world where subjects acting as farmers have to make a series of decisions over multiple periods that broadly reflect reality. A context-rich experimental setting can offer appropriate methods for drawing inferences about behaviour when investigating policy design (Suter and Vossler, 2013). Ultimately the experiment sets out to test, in contrast with a control treatment where only spot rights are traded, whether water license transfers or forward contracts yield more efficient market outcomes. Beyond the control group we implement two main treatments which only differ in the trading institution. The timing within one period is as follows:

1. Depending on the non-control treatment, a license or a forward contract auction takes place.
2. Farmers decide to sow (i.e. to produce) or not.
3. Farmers are told their (seasonal) water allocation for the current period.
4. A double-auction spot water market occurs, and in the forward contract treatment contracts are executed.
5. Production and consumption take place.

6. The bank balance is updated and interest is paid (borrowing occurs).

Reflecting typical conditions in countries with water markets, resources are allocated in the experimental environment on the basis of licenses owned and a range of seasonal conditions (i.e. dry, normal or wet).[3] Our modelled farmers' world consists of a dynamic general equilibrium model. The design of the model is governed by the trade-off between realism and simplicity. On the one hand, an overly simple model will not capture the relevant influences in farming and irrigation markets. On the other hand, an over-complicated framework leads to subject confusion and consequent loss of experimental control. A nice side-effect of using a model of intermediate complexity is that we obtain a time-independent equilibrium prediction which can be used as a benchmark to compare with observed behaviour. In what follows, we develop our model. To provide the reader with the easiest way to get a good feel for the experimental environment we fully present the model with the functional form assumptions and parameters used in the experiments.

3.1 The farmer's objective and the evolution of wealth holdings

A farmer's objective is to maximize expected lifetime utility. The future is uncertain, and after each period the probability of survival is δ with the probability $1-\delta$ that the farmer dies.[4] At each point in time the farmer's expected lifetime utility is fully characterised by the sum of past consumption utilities, which is sunk and current asset holdings. In our world with bequest motives it turns out that the optimal consumption level is time and wealth invariant. As we are not interested in farmers' consumption choices we fix consumption at the optimal level in the experiment and deduct that amount of money from farmers' bank accounts each period. The current wealth of

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[3] Within our experiment normal conditions provide the average water supply (e.g. two units per license). Dry conditions reduce water supply limit to one unit, while wet conditions increase it to three units per license.

[4] A probabilistic stopping rule is an alternative to discounting over an infinite horizon, which can be used to induce stationary equilibria and mimic infinitely repeated play (Carbone, 2006, Carbone and Hey, 2004).

farmer *i* in period *t* is thus modelled by the farmer's fixed consumption $c_{i,t}$ and their bank balance $b_{i,t}$. The lifetime utility of a farmer who dies in period τ is defined as:

$$V_{i,\tau} = \sum_{t=1}^{\tau} u\left(c_{i,t}\right) + \beta b_{i,\tau}. \tag{1}$$

This assumes that farmers have bequest motives, with β indicating the relative bequest motive importance. The bequest motive is required for c* to be constant over time; otherwise you would consume more when young since you would not want to risk having money left when you die. As in real life, farmers can also choose to borrow or deposit money units, produce farm output and/or trade water in each round to increase their final bequest value.[5] In the experiment the model boiled down to farmers maximising the expected bank balance at death. These options are all clearly explained to the participants in the experimental instructions and detailed more fully in the following sections.

Denote any net deposit in period *t* as $d_{i,t}$. Credit markets are assumed to be perfect. Therefore, both deposits and debts are subject to the same interest rate *r*, and a farmer's bank balance evolves as:

$$b_{i,t} = (1+r)b_{i,t-1} + d_{i,t}. \tag{2}$$

Given this structure we can calculate the expected value a net deposit $d_{i,t}$ will create:

$$\begin{aligned} EV\left(d_{i,t}\right) &= (1-\delta)\beta d_{i,t} \sum_{k=1}^{\infty} [\delta(1+r)]^{k-1} \\ &= \frac{(1-\delta)\beta d_{i,t}}{1-\delta(1+r)}. \end{aligned} \tag{3}$$

The period consumption utility function is standard and assumed to be increasing and concave. A farmer who chooses consumption in period *t* assesses the trade-off between consumption utility and the expected bequest and equalizes the expected marginal benefit of consuming and depositing returns from production:

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[5] Deposits simply accrued to the player's account at the end of each period. Borrowing occurred when any player ran out of funds during the experiment. In those instances the adjudicator added monetary units to the player's account so that they could continue. Any borrowed amounts were deducted from the final amount payable at the experiment's conclusion.

$$u\left(c_{i,t}^{*}\right)' = \frac{(1-\delta)\beta}{1-\delta(1+r)}. \tag{4}$$

3.2 Production technology and farm types

Farmers produce output using a simple production technology that requires input of water $w_{i,t}$ and seed. For simplicity we assume that production results in a farm-specific fixed cost K_i. Normalizing the output price to unity, the net revenue for given water input is:

$$\varphi\left(f_i\left(w_{i,t}\right) - K_i\right),$$

where φ is an indicator for the farmer's decision to produce and $f_i\left(w_{i,t}\right)$ denotes the sales value of the crop produced with the water quantity $w_{i,t}$. In order to capture differences in farm sizes and productivity we allow for two types of farms θ_i. Small farms mimic annual production systems with low fixed costs and lower output per unit of water, while large farms mimic perennial production systems with higher fixed costs but also higher outputs. Each market consists of four small and four large farmers indexed by *s* and *l*. For our experiments we use the following production function where θ_s = 1/3, θ_l = 2/3, and fixed cost K_s =55 and K_l =110:

$$f\left(w_{i,t}, \theta_i\right) := 100\sqrt{\theta_i w_{i,t}}.$$

3.3 Water licenses, rain and water markets

Common to both treatments is that water is not yet fully revealed for the season when farmers have to decide to produce (or not).Farmers hold water licenses (and potentially forward contracts) at that point in time though, which can assist in reducing their forward risk. Depending on the weather conditions a farmer will be allocated either one (dry), two (normal) or three (wet) units of water per license (e.g. similar to real seasonal water allocations). Denote the weather by $\alpha \in \{1, 2, 3\}$, which determines how much water is allocated per license. Farmers ex-ante do not know the realization of the weather but are aware of the associated probabilities Overall there are 24 water licenses in each market. In the license-trade treatment the number of licenses held per round will depend on previous trades, while in the forward-contract treatment each farmer holds three licenses fixed throughout the game. Once the weather is determined and water is allocated for the period a double-auction for water takes place.[6] Instead of solving for a Bayesian Equilibrium in the double-auction market we rely on previous theoretical and experimental work which shows that double-auctions reliably lead to efficient allocations (e.g. Friedman, 1984, Vernon, 1962, Wilson, 1985). Using the efficiency condition we calculate the equilibrium price and corresponding efficient allocation for all possible weather conditions and configurations of producing farmers.

We first derive individual demand for water. Clearly a farmer who has decided not to produce has zero-demand for water. Denote the price asked for seasonal water as p. The water demand of an individual producing farmer of type θ_i is thus given by:

$$\begin{aligned} w_{i,t}^{d} &= \arg\max_{w_{i,t}} f\left(w_{i,t}, \theta_i\right) - p w_{i,t} \\ &= \frac{2500\,\theta_i}{p^2}. \end{aligned}$$

Denoting the number of small and large farmers that have decided to produce as n_s and n_l respectively we can rewrite the total market demand as:

$$w_t^d = \frac{2500(n_s + 2n_l)}{3p^2}. \qquad (5)$$

With total supply equal to 24α we can solve for the equilibrium price and for the equilibrium allocation of water after an efficient double-auction has taken place:

$$w_t^{d*} = 24\alpha$$

$$p^* = \frac{25}{3}\sqrt{\frac{2n_l + n_s}{2\alpha}} \qquad (6)$$

$$w_{i,t}^{*} = \frac{72\theta_i\alpha}{2n_l + n_s}. \qquad (7)$$

3.4 The production decision

As discussed, a farmer has to decide to enter the market before knowing how much water they will have, which is risky. Denote the probability of state α (weather outcomes) to eventuate as γ_α. A risk-neutral farmer's optimal decision is to produce if their expected profit is greater than the profit

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[6] In reality, the production function for applied water would be a function of the weather, and may shift depending on the climate in any given period. The absence of this factor in the experiments may help to explain why the value of water may decline following any shock to the climate conditions.

from selling all their allocated water—without paying the fixed cost for production.[7] The optimal decision will vary across farm types and will depend on who else enters the market. We need to find a configuration of production decisions that constitute mutual optimal decisions. In our experiments we had two different sets of weather probabilities. Markets start off with $(\gamma_1, \gamma_2, \gamma_3)$ = (1/3, 1/3, 1/3) which represent the default climate. Later in the experiment a change to the climate parameters—the climate-change shock—provides less favourable probabilities $(\gamma_1, \gamma_2, \gamma_3)$ = (0.7, 0.15, 0.15). In the case of the default climate everybody should produce regardless of the distribution of licenses. Denote the number of water licenses firm *i* is holding in period *t* as $z_{i,t}$. If a small farmer holding $z_{i,t}$ licenses anticipates that all other farmers will produce, the expected payoff of producing is:

$$\begin{aligned} \mathrm{E}\Pi_i &= \mathrm{E}\left[f_s(w^*) - p^*\left(w^* - \alpha z_{i,t}\right)\right] - K_s \qquad (8) \\ &= 1.4 + 28.2 z_{i,t}. \end{aligned}$$

This exceeds the profit from not producing and spot selling water at equilibrium prices (with one less small farmer producing) which is equal to $27z_{i,t}$. Large farmers also should produce since their expected profit from producing is:

$$\mathrm{E}\Pi_i = 2.8 + 28.2 z_{i,t}.$$

This outcome is greater than $25.8z_{i,t}$, or the profit from selling all water in a market with one less large producer. Consequently, in equilibrium all farmers should produce regardless of their type or the allocation of water licenses. Moreover this is the only equilibrium, as with fewer farmers in the market the incentive to produce is higher due to lower water prices. Selling all one's water in markets with fewer producers is less attractive due to low resulting water prices from less demand and increased supply. This leads us to formulate our first proposition:

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[7] Note that the assumption of risk-neutrality is not crucial here for the structure of equilibrium. Faced with unexpected unfavourable shocks, participants might shift to overly risk-averse behaviour (Brown, Harlow and Tinic, 1988). However, with strongly risk-averse farmers we would get a smaller number of entrants in equilibrium. Thus risk aversion should not play a large role in our experiments where the stakes are moderate.

Proposition 1: *For the default climate with* $(\gamma_1, \gamma_2, \gamma_3)$ *= (1/3, 1/3, 1/3) all farmers are expected to produce and an efficient allocation of water is achieved through a double-auction. The efficient water allocation is* $w_s^* = 2\alpha$ *and* $w_l^* = 4\alpha$*. Total expected profit is* ***694.2****.*

Next we investigate what the stable configuration of farmers should be after the shock. It turns out that four different configurations can be sustained as an equilibrium: (n_l, n_s) = (4,2), (3,4), (4,1) and (3,3). Observe from Equations (5) and (6) that equilibrium price and total demand are identical as long as $2n_l$+n_s is constant. Therefore, the first two configurations lead to the same farmer profits. This is also true for the last two configurations. Whether the first or the last two configurations are equilibria depend on how the number of water licenses—or forward contracts—are distributed. If licenses are evenly distributed across all farmers then the first two configurations are the only possible equilibria. In the case of a lopsided distribution of licenses, where either most licenses are held by the large or by the small farmers, the latter two configurations (with less farmers producing) result in equilibria. Table 1 shows the possible equilibrium configurations where $\Delta\mathrm{E}\Pi_\theta$ is the expected profit difference between producing and not producing for a farmer of type θ_i, while $\mathrm{E}W$ denotes the expected total surplus created.

Table 1: Equilibrium configurations after the climate shock

(n_l, n_s)	$\Delta\mathrm{E}\Pi_l$	$\Delta\mathrm{E}\Pi_s$	p^*	(w_l^*, w_s^*)	$\mathrm{E}W$
(4,2), (3,4)	$2.3z_{i,t} - 5.2$	$1.1z_{i,t} - 2.6$	$\frac{19.5}{\sqrt{\alpha}}$	$\left(\frac{24\alpha}{5}, \frac{12\alpha}{5}\right)$	498.2
(4,1), (3,3)	$2.4z_{i,t} + 0.5$	$1.2z_{i,t} + 0.2$	$\frac{25}{\sqrt{2\alpha}}$	$\left(\frac{16\alpha}{3}, \frac{8\alpha}{3}\right)$	499.4

This leads us to our second proposition:

Proposition 2: *After the climate shock for* $(\gamma_1, \gamma_2, \gamma_3)$ *= (0.7, 0.15, 0.15), depending on license distributions, four equilibria are possible characterized by* $2n_l^* + n_s^*$ *= 10 or* $2n_l^* + n_s^*$ *= 9 with water usage* $w_s^* = 24\alpha/(2n_l^* + n_s^*)$ *and* $w_l^* = 48\alpha/(2n_l^* + n_s^*)$*. The total profit is either **498.2*** $(2n_l + n_s = 10)$ *or **499.4*** $(2n_l + n_s = 9)$.

Here it is worth mentioning that our equilibrium concept is that of a stable situation where *ex-post* nobody can do better by changing their production decision. While this sounds like the standard Nash concept, it is not. Note that in our experiments farmers do not know the cost, production functions or license distribution for other farmers. Also no objective prior beliefs on these are induced. So there is ambiguity and the classic definition of a Bayesian game does not apply. The ambiguity faced by our subjects makes it very unlikely that equilibrium is actually reached. In our view this is an appealing feature of our environment as it allows us to introduce at least some of the complexity faced by real-world farmers. Moreover with our environment we will be able to distinguish between inefficiencies that arise from the farmers' decision to produce (or not) from those that arise because of water markets not being able to efficiently distribute water among producing farmers.

3.5 Pre-production trading

We now look at the role of pre-production water trading. Recall that we have two treatments. In one treatment farmers can trade licenses once a period. This trading takes place before production decisions have to be made. In the second treatment, instead of license trade forward contracts can be negotiated. In the forward market farmers can agree on trading volumes and prices conditional on the expected weather state (i.e. the allocation of water per license). These forward contracts are signed before production decisions are made. In what follows we show that both institutions should have no influence on efficiency under the assumption that spot markets work perfectly, and farmers follow the equilibrium production decisions outlined above.

Value of a water license and license auctions

Having determined how many and which farmers are expected to produce we can determine the value of a license for the first treatment. License auction prices should equal the expected benefit that a license provides. The immediate cash value of a unit of water is equal to its trading price. Therefore the expected cash equivalent for water that a license holder is entitled to in any given period is equal to:

$$\mathrm{E}C = \sum_{\alpha=1}^{3} \frac{25\alpha\gamma_\alpha}{3} \sqrt{\frac{2n_l + n_s}{2\alpha}}.$$

If the farmer dies at the end of period *t* then the license generates pay-off $\beta \mathrm{E}C$; where β is the parameter that measures how much the farmer values profits. If a farmer survives the next period, but then dies, the license generates a monetary equivalent this period and also one for next period. Additionally the money earned this period will attract interest. Therefore a farmer who lives exactly two periods gets the benefit of $\beta \mathrm{E}C(2 + r)$. Thus, summing the probability-weighted expected returns yields the expected value of a license:

$$\begin{aligned} V_z &= \beta \mathrm{E}C(1-\delta)\textstyle\sum_{T=1}^{\infty} \delta^{T-1} \sum_{t=1}^{T} (1+r)^{t-1} \\ &= \frac{\beta \mathrm{E}C}{1-\delta(1+r)}. \end{aligned} \tag{9}$$

With the parameters defined (i.e. a survival probability δ = 0.9, an interest rate of *r* = 0.05 and a valuation per dollar earned of $\beta = 1$) we can now calculate the value of a license conditional on being in the pre- or post-shock phase. In the license trade treatment the value is an equilibrium prediction for the price licenses are traded at. This leads us to our next proposition:

> ***Proposition 3:*** *The value of a license before the climate shock for* $(\gamma_1, \gamma_2, \gamma_3)$ *= (1/3, 1/3, 1/3) is equal to* ***512.94****. After the shock for* $(\gamma_1, \gamma_2, \gamma_3)$ *= (0.7, 0.15, 0.15) the value of a license lies between* ***376.68*** *(if* $2n_l + n_s = 9$*) and* ***397.05*** *(if* $2n_l + n_s = 10$*).*

A reason for the decline in license values post-shock could be associated with the resource-share nature of entitlements here, which means that water is more valuable when plentiful due to the marginal value of additional production. Thus, under a reduction in supply treatment, the perceived value of the entitlement may decrease. Note our implicit assumption that the water auction within a production period works perfectly. This implies that one water license has exactly the same value for all farmers regardless of their type or their current holdings. For this reason no license trade should take place as there are no gains from trade. Moreover, under this assumption the license market has no role to play in improving over-all efficiency. With the value of a license calculated we can next calculate the equilibrium price. Recall that the opportunity cost of spending *d* units of money today is given by Equation (3). In equilibrium, the price should be equal to the deposit amount that would generate the same value as a license:

$$\frac{(1-\delta)\beta p_z^*}{1-\delta(1+r)} = \frac{\beta \mathrm{E}C}{1-\delta(1+r)}$$

$$p_z^* = \frac{\mathrm{E}C}{1-\delta}.$$

Using our parameter values we can thus calculate the equilibrium license prices for the periods before and after the shock. This leads us to our final proposition:

Proposition 4: *The equilibrium price for a license before the climate shock for* $(\gamma_1, \gamma_2, \gamma_3)$ *= (1/3, 1/3, 1/3) is equal to* ***282.12***. *After the climate shock for* $(\gamma_1, \gamma_2, \gamma_3)$ *= (0.7, 0.15, 0.15) the equilibrium price of a license lies between* ***207.17*** *(if* $2n_l + n_s = 9$*) and* ***218.38*** *(if* $2n_l + n_s = 10$*).*

Forward contracts

The opportunity to write forward contracts conditional on stochastic weather outcomes simply duplicates the spot market, as that market unfolds once the weather is determined. The main difference is that when forward contracts are written farmers have not yet committed to produce (or not). As long as the equilibrium (i.e. production decisions and water auction outcomes) is anticipated by farmers, forward contracting is a perfect substitute to buying and selling water in the spot market; as discussed by Newbery and Stiglitz (1985). Conditionally then, forward contracts do not have the capacity to influence efficiency. This result also does not depend on the assumption of risk-neutral farmers. Even if farmers are risk-averse, but foresee the outcomes in the water market, forward contracts have no special role to play. Forward contracts may instead be viewed by farmers as insurance contracts. Importantly though in the experiment they cannot provide more insurance than that provided by a working spot market.

The role of pre-production trading under off-equilibrium play

While pre-production trading has no role to play if the spot market works perfectly—and farmers could anticipate this—it may have an impact once we leave the equilibrium path. Suppose that a farmer is unsure what the spot price will be for different states of nature. In that case, a forward contract may provide valuable information and insurance as it takes place before the decision to produce (or not) has been made. For this reason we conjecture that forward contracting might be helpful in inducing optimal production decisions. The alternative license trade instrument addresses another concern farmers might have with respect to spot markets. Suppose some farmers fear that the market will not be liquid enough to support their purchase of seasonal water when required. Then, some farmers might not produce even if it were efficient to do so. In this case trading licenses might help, since purchasing additional licenses may insure farmers against incomplete spot water markets. *Ex-ante* it is unclear which of the two pre-production trading institutions performs better with respect to efficient production decisions and water allocations. This provides valuable justification for the experiment treatments used herein to test different water market product designs and mixtures.

4. EXPERIMENTAL DESIGN

Table 2 summarizes the experimental design. Subjects (students) were instructed to think of themselves as farmers with a demand for water each season and a profit-maximizing objective.[8] They were able to utilize license/forward contracting and/or spot market trade to manage water demand, risk, and to maximize their bequest (i.e. their end payout).

Table 2: Experimental design

Treatment	Pre-shock	Post-shock
❶ Spot trade only (control group)	3 markets with 8 participants each	3 markets with 8 participants each
❷ Water license trade (with spot trade)	10 markets with 8 participants each	10 markets with 8 participants each
❸ Forward contract trade (with spot trade)	9 markets with 8 participants each	9 markets with 8 participants each

Recall there are two types of farms (four of each kind) in a market, with different production functions. One production function mimicked relatively low values for water and elastic demand (e.g. annual crop farmers such as wheat growers), while the other mimicked relatively higher values for water and inelastic water demand (e.g. perennial crop farmers such as fruit-tree growers). Subjects were randomly assigned to different farm types. Our treatments examined the effect of different pre-production trade mechanisms on efficiency. Subjects participated in one of the three treatments only, and all treatment subjects were exposed to the climate shock after seven periods. In all cases spot trade allowed participants to adjust their water holding for production after receiving information on their seasonal (period) water allocation.

4.1 Structure of a production period

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[8] As discussed above the experimental design forced them to deal with some of the complexity faced by real farmers. Although common, the use of students in our experiment may draw criticism and concerns about the relevance of our findings in natural agricultural settings. It is possible that differentials between laboratory and natural settings may be over or under exaggerated (Levitt and List, 2007). Empirical evidence of the findings discussed herein would benefit greatly by capturing real farmer behaviour—as planned for future research rounds.

Table 3 summarizes the timing of a production period. Each subject began the experiment with equal units of: water licenses (three shares), money in their bank account (200 monetary units), and a fixed annual consumption requirement to survive (50 monetary units). Prior to starting the experiment subjects could ask questions of the adjudicators and participate in two practice rounds.[9]

Table 3: Timing

❶ **Spot trade**	❷ **License trade**	❸ **Forward contract trade**
Instructions and training rounds Initial endowment of water and opening bank balance *(no Stage 1 decision)*	Instructions and training rounds Initial endowment of water and opening bank balance **Stage 1:** License auction - License shares updated	Instructions and training rounds Initial endowment of water and opening bank balance **Stage 1:** Forward contracts - For dry, normal or wet conditions - Forward contracts established
Stage 2: Production decision - Seasonal allocation outcome announced	**Stage 2:** Production decision - Seasonal allocation outcome announced	**Stage 2:** Production decision - Seasonal allocation outcome announced
Stage 3: Spot market auction and production update	**Stage 3:** Spot market auction and production update	**Stage 3:** Spot market auction and production update - Conditional (e.g. wet) forward contracts executed - Penalties apply for default[10]
Stage 4: Results Profit/loss calculated, interest paid and consumption subtracted. Random game-ending draw - game continues or ends	**Stage 4:** Results Profit/loss calculated, interest paid and consumption subtracted. Random game-ending draw - game continues or ends	**Stage 4:** Results Profit/loss calculated, interest paid and consumption subtracted. Random game-ending draw - game continues or ends

Once the experiment had commenced subjects were not allowed to communicate with one another. In the license treatment subjects could buy or sell water licenses using a double-auction market; where subjects could submit bids and asks and accept current bids and asks. As the experiment progressed, previous sales-price information was provided as a reference. Alternatively in the forward contract treatment, subjects could create conditional agreements to buy or sell water units under dry, normal or wet water supply outcomes in the season ahead. Subjects could post forward contract bid prices for single water units that were contingent on a

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[9] The inclusion of practice rounds did not in our opinion generate confounding training effects similar to those reported by Godby et al. (1997). A full set of instructions are included as an appendix to this article.

[10] Participants unable to meet forward contract obligations (if executed) were penalised by having water purchased on their behalf at the spot price for that round, which was then used to fulfil the contract. This cost was then subtracted from their bank account at round’s-end.

certain weather condition materializing, or enter forward contracts by accepting already posted bids. At the conclusion of this stage water license holdings were updated or forward contracts were established in readiness for the season outcome.

Stage two required subjects to decide whether or not they would enter into production for the round, and pay the associated fixed costs. To assist this decision each subject was provided with a table identifying the probability of different climate outcomes (dry, normal or wet), a corresponding volume of water allocation that would be provided under those conditions, and a table of revenue outcomes from farm water use in the case that they decided to produce. Time was provided for subjects to assess the relative advantages of differential water use (i.e. use in production or trading). Once these decision rounds were completed a random draw selected the seasonal outcome, subsequently communicated to subjects. As discussed, before the shock the probabilities of dry, normal or wet weather were uniformly one-third. After the climate-change shock dry condition probability increased to 70%, while normal and wet conditions each prevailed with a 15% probability. The change in weather-state probabilities was clearly communicated to subjects in all treatments. In the forward contract treatment only forward contracts (e.g. contracts stipulating dry season execution) that matched with the resultant seasonal outcome (e.g. dry seasonal conditions) needed to be honoured. All other forward contracts were considered forfeit and no further action was needed.[11] Any subjects that executed contracts for more water than they had/received were penalised for not being able to meet their obligations and 'forced' to buy water in the spot market at the average price for that round, to cover that shortfall. All subjects were made well aware of this via the instructions and adjudicator statements prior to the experiments.

In stage three subjects were given the opportunity to adjust their water holdings through spot trade. Again a double-auction system allowed subjects to buy or sell whole units of water via a bid

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[11] As such, there was no transaction cost associated with these contracts that would be forfeit if they did not proceed. On that basis, the product here may arguably be closer to an option contract. On reflection, it would have been useful to include some transaction costs into the experiment, and this is intended in future treatments.

and ask process (similar to how water is actually traded). All units of water held were automatically used for production. Water could not be carried forward into subsequent rounds of the experiment. Finally in stage four of the experiment the outcome of decision-making over the course of the round was calculated for each subject. Information included: the opening bank balance; interest earned or paid; consumption during the period; water license holdings traded or forward contracts entered into; farm production and water trade outcomes; as well as the closing bank balance. The appendix document provides greater detail on the process.

4.2 Experimental procedure

The experiment was conducted at the University of Adelaide's experimental economics laboratory AdLab using the software z-Tree (Fischbacher, 2007). Subjects were recruited from the University of Adelaide student population between September 2012 and March 2013 with the help of the online-recruiting software ORSEE (Greiner, 2015). Each subject interacted anonymously with other subjects in a market of eight participants. In our sessions we had up to three markets operating simultaneously. Overall we had 22 markets across our treatments all with a stochastic stopping rule. The probability of stopping after any period was 10 percent. We used three ex-ante draws for all treatments that yielded 13, 14 and 15 total periods.[12] In total, approximately 1500 students listed on the system were invited to participate in the experiments, and of those the first 176 to sign up were recruited. Each subject stayed in the same group for the whole experiment. Sessions lasted two and a half hours on average, and each period played earned the subject AUD$1.50. For every additional 50 points earned in the game we paid AUD$1.00; held constant for all subjects. The average earning was around AUD$37.00 inclusive of a turn-up fee, and students were paid in cash. Finally, at the end of each session subjects were asked to complete some concluding survey questions on their demographics.

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[12] Note that the number of periods was slightly above the expected number given the stopping rule, which was 11. However the draws observed were not extreme. The probability of observing at least 15 periods, e.g. is still roughly 23 percent.

5. RESULTS AND DISCUSSION

By acquiring water licenses farmers increase their water allocations conditional on the weather. Farmers owning a large number of licenses may have reduced uncertainty and incentive to purchase further water in the market. Forward contracts have a similar function. Farmers can—before they decide to produce (or not)—purchase future access to water from other farmers, thereby reducing uncertainty. Note that theoretically neither of the two institutions is required in order to achieve efficiency. In a world of fully rational farmers with corresponding rational expectations a spot water market should be sufficient. We conjecture that if this is not the case limited information and cognitive abilities as well as decision errors are likely to lead to inefficient production decisions. If this is the case, however, then license trade and forward contracts have the potential to enhance efficiency.

To structure the results we first examine the distribution of trades across the three products for each period (Figure 1).

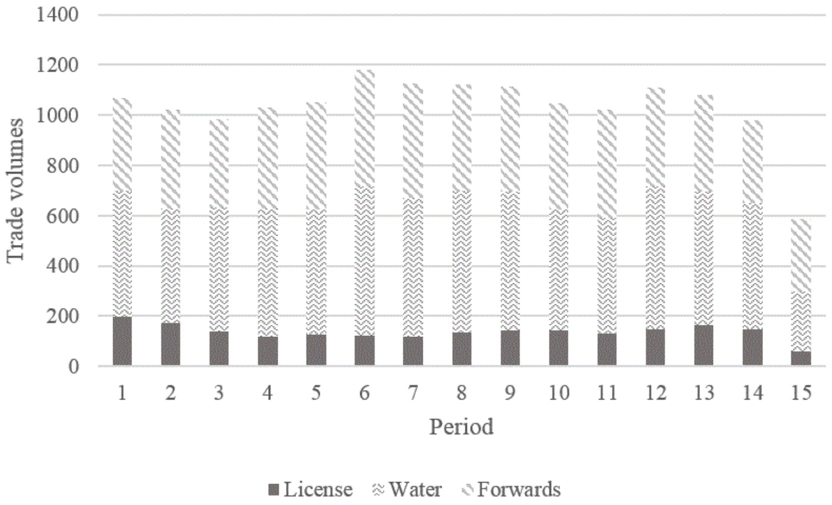

Figure 1: Trade volumes for each water product, by period

We can see that trade of both spot water and forward contract products overshadow that of licenses, although early trade of licenses can be relatively high. Some license trade continues in each period as the farmers seek to achieve their objectives. But which of the three institutions achieves a higher level of efficiency? An analysis of this question will establish the main result of our paper. We then search for the root causes of that result by looking at the functioning of the experimental water markets, production decisions of farmers and their trading behaviour in license and forward contract markets.

5.1 Total surplus

The first question we want to answer is how different trading institutions impact on overall efficiency. To achieve this we take the total profit (surplus) generated in a market per period by a group of subjects as the dependent variable and estimate panel models with a random effect on the group level. As we do not have consumers in our experiment from which to draw an estimate of their utility created by water allocations during the experiment we simply calculate the producer surplus, which in this case is their profit. We are initially interested in how forward contracting impacts on profitability compared to spot markets alone using license trade as a base. We control for weather and learning dynamics through two models: 1) featuring period dummies and 2) featuring a dummy for the post-shock phase after period seven (Table 4).

There is a significant treatment effect that does not depend on the specification. Forward contracts are on average more efficient than license trade by about 35 to 36 monetary units. Further, forward contracts are on average 22 monetary units higher than spot market trades. This efficiency difference across treatments is significant ($P<0.001$) and amounts to about 5% of the total expected equilibrium surplus before—and about 7% after—the climate shock.

Table 4: Random-effect GLS estimation of water market profits

	Model 1		*Model 2*	
Treatment	*Coeff.*	*Std. Error*	*Coeff.*	*Std. Error*
License trade (base)	—	—	—	—
Forward contract	35.77***	11.05	36.36**	10.73
Spot market only	14.33	15.55	14.77	15.13
Weather (Base = dry)				
Normal	352.42***	8.99	350.03***	8.28
Wet	599.01***	7.74	596.70***	7.15
Post-shock	-		14.71**	6.17
Period Dummies	Yes		No	
Constant	290.26***	13.74	295.15***	8.61
N	315		315	
ρ	0.124		0.119	
R^2	0.966		0.965	

*** = significance at p<0.01

Result 1: *Forward contracts lead to more efficient market outcomes than spot market and/or license trade. The effect is highly statistically significant and economically relevant.*

Next we compare the level of efficiency achieved with that in the constrained optimum which is equal to *(1 – relative efficiency)*100*. In Table 5 we use the predicted values for the profit from model two above and compare it to the profit that would prevail under equilibrium play.

Table 5: Profits relative to constrained optimum

		Optimal profit	***License***	***Spot market****	***Forward contracts***
	Dry	**319.80**	293.63 (0.1559)	301.60 (0.0961)	307.58 (0.1416)
Pre-shock	Normal	**725.64**	665.05 (0.0633)	666.71 (0.0603)	688.86 (0.0407)

	Wet	**1037.06**	868.50 (0.0860)	949.12 (0.0698)	939.33 (0.0616)
Post-shock	Dry	**353.53**	327.12 (0.0703)	310.71 (0.0963)	329.99 (0.0983)
	Normal	**705.00**	636.25 (0.0540)	655.69 (0.0154)	686.69 (0.0365)
	Wet	**974.70**	880.20 (0.0428)	885.50 (0.1374)	961.99 (0.0515)

* Standard deviations reported in parentheses.

The difference between optimal and treatment profits are generally largest where more water is available. Spot markets alone generally underperform other institutions pre-shock, except in dry conditions. Further, license trade can lead to poorer outcomes particularly if bad choices occur early (e.g. premature selling). Multivariate testing of the treatment outcomes across periods supported the differential evolution of treatments over the course of the experiment (*ProbF>0.000*). The constrained optimum is based on farmers producing without knowing how much water will be available. Wrong market entry decisions can lead to farmers doing better under certain weather conditions than they would in equilibrium; while they may equally do worse in others. Post-estimation Wald testing for weather, treatment and group effects determined that on average across all weather conditions distorted market entry reduced market welfare. Generally we find that forward contracting water markets achieve closest to constrained optimum results, especially after the climate shock.

Result 2: *Forward contracting water markets achieve closest to constrained optimum results especially after the climate shock.*

5.2 Causes of the welfare losses

Here we adopt the classic definition of welfare losses as the reduction in consumer and producer surplus that results from too much (little) production and consumption of, in this case, farming resources. Expanding on these two dimensions of the allocation problem (i.e. the production decision and the allocation of water) can be instructive for decomposing the welfare losses into those stemming from distorted production decisions and those caused by water markets not properly allocating the water. We will look at these two dimensions in turn, starting with distorted production decisions.

Production decisions

Recall that before the shock constraint optimality requires that all farmers decide to produce. Regardless of the current number of water licenses held a fully rational farmer who foresees the outcome in the water market would decide to produce. Having all farmers produce maximizes the expected total profitability—where the expectation is calculated over the different weather conditions before they are determined. Thus, before the shock a farmer not producing creates a welfare loss in expected terms. After the climate shock less water is available, and therefore not all farmers should produce. As shown above there are a few different configurations with respect to the number and type of farmers who decide to produce, which generate equilibria; recalling that in each experiment group we have equal numbers of small and large farms.

The equilibrium condition is $2n_l + n_s \in \{9, 10\}$, where n_s and n_l are the number of small and large farmers that produce. The profit for all potential equilibrium configurations is approximately the same: (either 498.2 or 499.4). Therefore, whenever $2n_l + n_s < 9$ we experience a welfare loss due to too *few* farmers producing. In the case $2n_l + n_s > 10$ we also get an efficiency loss due to too *many* farmers producing. Table 6 reports the fraction of markets with too-much, an optimal degree of (efficient), or too-little production entry by treatment for the pre- and post-shock phase.

Table 6: Number of producing farmers relative to optimum

		Spot market	*License*	*Forward*
Pre-shock	Too little	52.38	87.41	73.02
	Efficient	47.62	12.86	26.98
	Too much	-	-	-
Post-shock	Too little	19.05	59.46	27.27
	Efficient	38.10	32.43	48.48

Too much	42.86	8.11	24.24

Pre-shock all treatments tend toward under-production when in theory pre-shock is the optimal time to produce. Spot markets perform best. But post-shock there is higher variability in the spot market and license treatments, while forward contracts achieve the most efficient outcome between balanced over- and under-production. The effect is considerably smaller in the forward contract treatment, as confirmed by multivariate testing of the means (*ProbF>0.000*), which determines which combination of treatments performs the best out of all possible combinations. In the post-shock phase there is still systematically too-much entry in the spot market and too-little entry in the license trade treatment, while close to half the sessions in the forward contract treatment exhibit an optimal mix of farmer production.

Result 3: *Efficient configurations of production decisions occur more often in the forward contracts treatment.*

Water allocation among producing farmers

The second source of welfare loss is the misallocation of water amongst farmers that have entered the water market. If the double-auction spot market for water worked perfectly, regardless of the treatment and the number of farmers who decided to produce, then there should be no welfare loss other than that from suboptimal production decisions. Our findings show that there are considerable welfare losses dependent on weather and treatment. Comparison of welfare across weather conditions, treatments and configurations of producing farms is therefore needed. For this purpose we concentrate on profits generated as a fraction of the maximum possible profitability given weather and production decisions (Table7). Random-effects Tobit models are used due to the censored nature of the efficiency outcomes following production decisions.

Table 7: Random-effects Tobit estimates of trade product’s relative efficiency

Treatment	*Coeff.*	*Std. Error*

License trade (base)	—	—
Forward contract	0.008	0.019
Spot market only	-0.022	0.025
Initial license endowment	-0.004***	0.001
Weather (base = dry)		
Normal	0.037***	0.011
Wet	0.030***	0.009
Period	0.006***	0.002
Post-shock	0.000	0.016
Constant	0.883***	0.017
N	315	
ρ	0.143	
log L	377.884	

*** = significance at p<0.01

In general our double-auction institution for water trading does very well. On average 92.9% of the maximum profit is actually realized; albeit with differences across the treatments. The double-auction in the license trade treatment only delivers 90.6% of potential profit, which is significantly lower than the 95.5% in the forward contract treatment. At first this is somewhat surprising as the same double-auction is used in both treatments. In Table 7 the relative efficiency created by a market is the dependent variable, and independent variables include a dummy for: the forward contract treatment; the variance of license holdings in a market; controls for weather and the climate shock; as well as a time trend. The forward contract treatment dummy is not statistically significant, although it is positive. Instead the significant differences observed in the relative efficiencies across treatments come from a negative effect of unequal distribution of licenses in the license trade treatment. The efficiency that double-auctions can provide is increased where there is greater relative equality in the distribution of water licenses. Note that unequal distributions of water licenses can only occur in the license trade treatment. This finding is contrary to other experimental results involving double-auctions where monopoly and monopsony parties may exercise market power (e.g. Muller, Mestelman, Spraggon and Godby, 2002). The critical difference in this experiment is that the unequal distribution is generated by poor early trade decisions, not uneven initial distributions consistent with monopoly, monopsony or oligopoly market structures. Thus, where the distribution in our experiment remains relatively equal, subjects are not able to exercise undue market power over one another.

Result 4: *The created surplus relative to the maximum for given production and weather decisions is higher in the forward contract treatment. The double-auction institution produces less efficient water allocations if the experiments tend toward unequal license distributions.*

Table 7 results also show the relative inefficiency is greater if water is scarce (i.e. weather conditions are dry). Moreover there is a time trend. With increasing subject experience, the double-auction does a better and better job of allocating water. Over the full duration of the experiment (13 to 15 rounds) the relative efficiency increased by about 9%.

Decomposing the total welfare loss

We next decomposed the welfare loss into that caused by production decisions and that caused by water market inefficiencies. The profit that could be optimally achieved for a given weather situation was calculated and then subtracted from the welfare loss in the water market (conditional on the entry decision). The remaining gap between this figure and the actual welfare is the loss that resulted from suboptimal entry decisions of farmers. Figure 2 shows the result by treatment, and before and after the shock, as a fraction of the total available profits. The forward contract treatment does better in all respects as supported by multivariate testing for weather, group, period and shock effects (*ProbF>0.000*). Losses due to both production and water market entry decisions are smaller, both before and after the shock.

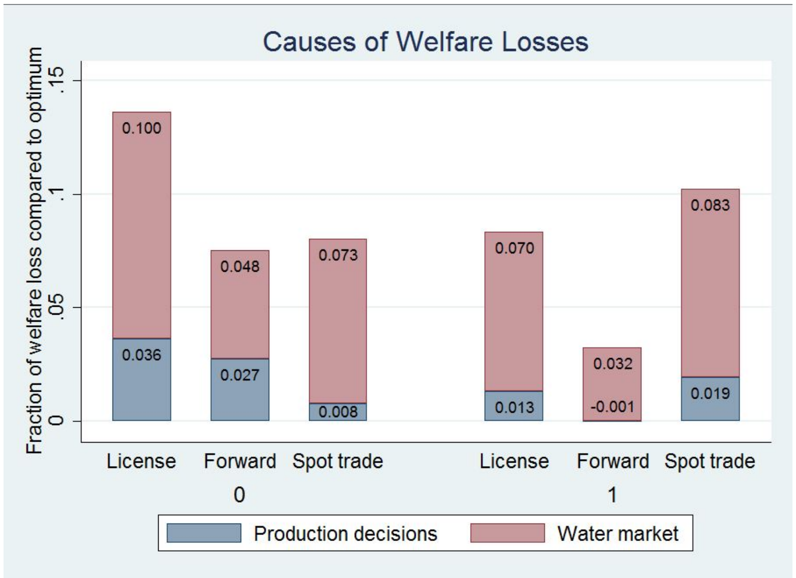

Figure 2: The causes of welfare losses

> ***Result 5:*** *Forward contracts achieve more efficient production decisions and lead to more efficient water markets, both before and after a climate shock.*

5.3 License prices

Finally we considered water license pricing. Recall that the equilibrium price of a license was calculated at 218 monetary units before—and 207 monetary units after—the shock. Since it is very hard for subjects to ex-ante estimate the value of a license we would expect them to have quite heterogeneous beliefs about prices. Indeed mean trading prices of licenses were off by about 100% before the shock, while prices were in the right vicinity after the shock. Again we observe prices rising after the shock instead of dropping as prescribed by equilibrium. Subjects seeking water access after the climate shock reduced the expected amount of water per license. Thus any mispricing of water licenses (Figure 3) does not necessarily reduce efficiency.

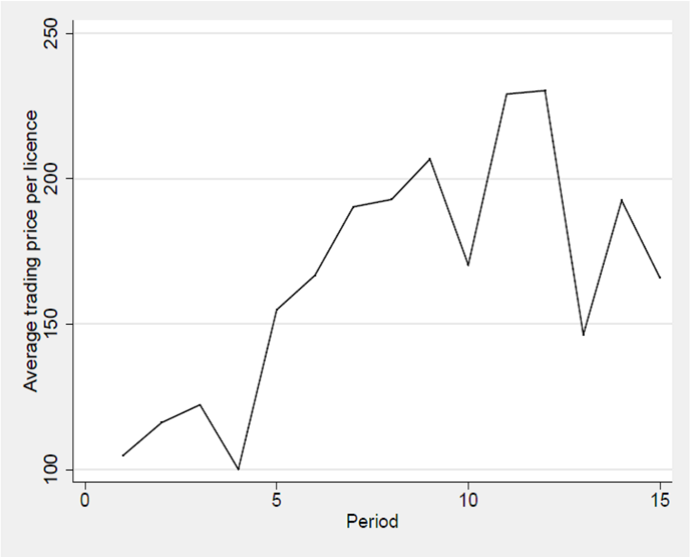

Figure 3: Average license prices

The mispricing of licenses in conjuncture with the working of the water market does lead to welfare losses. If mispricing arises from substantial heterogeneity in the beliefs about the value of a license then license trading leads to a concentration in the hands of those with the highest value. Above we have seen that water markets become less efficient the more unequal the distribution of licenses. So indirectly license trade leads to higher welfare losses than forward contracts. Another socially undesirable effect promoted by license trade is that due to the mispricing of licenses wealth inequality becomes large.

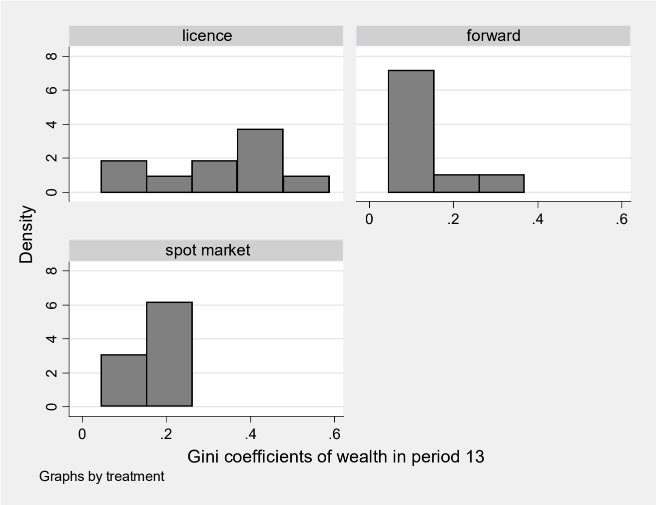

Figure 4: Distribution of Gini coefficients

Figure 4 shows the distribution of Gini coefficients (the distribution of wealth subjects had accumulated in period 13 for all 22 groups of eight farmers) by treatment. On average, in the license trade treatment the Gini coefficient was almost three times as large as in the forward contract treatment (0.32 vs. 0.11) and the difference is highly statistically significant ($p<0.002$, Mann Whitney U-Test, two-sided). Forward contracting also moderately outperformed the spot market, as expected.

Result 6: *Licenses are mispriced which leads to inequality in license holdings, increased inefficiency in the water market, and larger wealth inequality than in the forward contract treatment.*

6. CONCLUSION

The use of water markets is advocated as a useful economic instrument to address growing water scarcity around the world. This study reports on a series of experiments that compare the efficiency properties of three types of water market product that aim to efficiently allocate scarce water and influence production decisions. These product types include: a spot market (control group), a water license market and forward contracts—both with later stage double-auction clearing markets. In our experimental environment forward contracts generally fared better and improved market efficiency. This was particularly true after an unanticipated climate shock reduced expected water supply. License trading suffered from the problem that the value of water licenses is difficult to calculate, as it is a claim over an uncertain future stream of water allocations. The heterogeneity of beliefs about the value of a license led to a concentration of water licenses in the hands of those who believed it would be worth more in future periods. In the later double-auction stage market trade subsequent unequal allocation distributions led to welfare losses; since the later double-auctions tended to produce less efficient outcomes under uneven water distributions. Moreover, poor early license trading also led to a subsequent high degree of wealth inequality among farmers.

Forward contracts did not suffer from these problems and were—for a given number of farmers who decided to produce—significantly more efficient. A second advantage of the forward contract market was that it improved production decisions and therefore social welfare.

This paper strongly suggests that forward contracts are the better market institution to assist market participants to deal with water supply uncertainty. However, a few points of caution are in order. The nature of our study implies that our results should be only interpreted qualitatively. Moreover, while we tried to make the environment as generic and general as possible, we still had to make some design choices which could have influenced the results. An example of this is the split-nature of the climate shock treatment, which may make it difficult to disentangle learning effects from our interpretation of the results. Further, since the fixed costs in this experiment were only associated with seed costs, and do not consider longer-term impacts from entitlement trade such as farm entry and exit decisions, future variations on this research would seek to examine those issues more closely. For this reason some further research that makes different choices would be valuable. Further beneficial research may include replicating these experiments with actual farmers to generate robust empirical support for these findings. Other variations could include introducing transaction costs (as done in Lefebvre et al., 2012 in another context) and examining variations with the length of training periods to disentangle any learning effects across participants. Furthermore, our novel dynamic modelling approach could be used to evaluate the expected performance of different instruments in specific regions. Estimating intertemporal rainfall distributions and production functions for real world regions and embedding it in our experimental framework could generate quantitative predictions of many key outcomes (efficiency, production level, and evolution of wealth and income distributions) conditional on the market instruments used. Similarly, our framework can be used to more realistically test which market institutions are better suited to induce necessary structural change in response to a changing climate.

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