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WATER RESOURCES DEVELOPMENT:
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Effectiveness of a Market-Based Instrument for the Allocation of Water in a Tropical River Environment[1]

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Abstract—The seasonal nature of Australia's tropical rivers means that connected groundwater aquifers are an important source of both consumptive and non-consumptive water, particularly during the dry season. The management of these common pool groundwater resources is one of the predominant water issues facing northern Australia. A national program of water reform stipulates the expansion of water trading as a key instrument for water allocation. The effectiveness of new institutional arrangements such as water markets will be determined mostly by how well they coordinate with local environmental requirements, local institutions and local norms. This paper describes a novel application of combined field work, institutional analysis, experimental economics and agent-based modeling to the analysis of a potential water market in the Katherine region of the Northern Territory, Australia. The effectiveness of different versions of the policy instrument is assessed in light of local conditions. Instruments that enable personal relationships and local institutions and norms to play a role in water management are found to be more effective in terms of both farming income and environmental impact.

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The management of common pool groundwater resources is one of the predominant water issues facing northern Australia. The seasonal nature of most tropical rivers means that groundwater is an important source for both consumptive and non-consumptive uses of water, particularly in dry periods. This is an important characteristic that differentiates Australia's tropical rivers from the river systems of temperate Australia. While most tropical river catchments in Australia are largely undeveloped, there is increasing interest in agricultural development in the region.

Institutional failure has been identified as the main impediment to the management of water in Australia [30, 34]. In response, Australia's national program of water reform, the National Water Initiative (NWI), stipulates "the expansion of the trade in water resulting in more profitable use of water and more cost-effective and flexible recovery of water to achieve environmental outcomes" [8]. While water trading has been operational in southern parts of Australia for the past two decades, very little is known about how water markets may operate in a tropical river setting and the economic, social and environmental outcomes they may lead to.

The exchange of tradable water rights is the water management policy instrument endorsed and ratified by the National Water Initiative. This institutional arrangement is designed to encourage changes in behavior through the price signals of markets, as opposed to the directives associated with regulatory and centralized planning approaches to environmental management [40]. The potential advantage of such approaches is that they can achieve environmental goals at a more affordable cost to the community than can regulatory approaches. The common pool nature of water means that while license-holders do own a tradable property right to use a specified volume, there is also an aspect of the resource that is non-excludable and subtractable in that it provides benefits that are mutually shared by these license-holders [43]. Examples of these benefits are healthy water quality and the provision of ecosystem services. Managing the outcomes of water extraction from such resources is challenging and is likely to require an institutional arrangement that combines both economic instruments and community involvement [7, 34].

Institutional theory suggests that common pool resources can be effectively managed if there are information and communication options available to those using the resource [26, 28, 44]. This is supported by empirical evidence showing that the provision of a formal and controlled forum for discussion leads to robust and effective voluntary social contracts with high levels of contract adherence [6, 24, 31, 43]. Compared to impersonal communication, face-to-face communication has been shown to be the most effective means of

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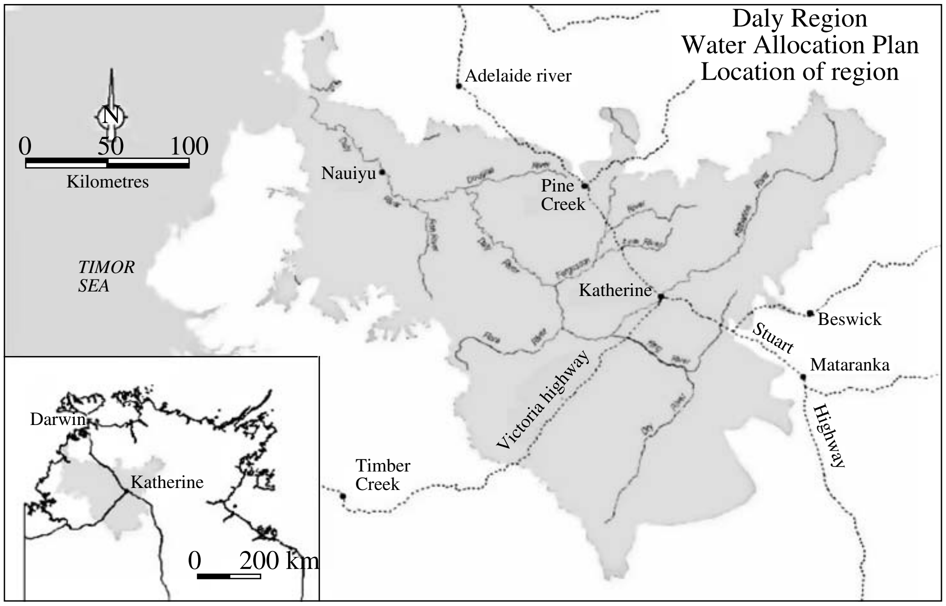

Fig. 1. Map of the Katherine-Daly River region (Northern Territory Government 2004).

promoting and reinforcing the formation of social compacts [28] and sanctions imposed on those who default on a group agreement are also possible and may further reinforce cooperative strategies [25, 32]. Smith [38, 39] and T. Tisdell et al. [43] have found that the provision of information is necessary to achieve effective management, but without a coordination mechanism is unlikely to be sufficient in itself.

If those crafting or changing the rules of a formal instrument do not understand how particular sets of rules affect actions and outcomes in a particular ecological and cultural setting, these rule changes may result in rapid, unexpected, and possibly perverse outcomes [27], In some cases, the introduction of a market institution where there were originally effective social contracts can erode the social contract and/or result in other perverse outcomes [35]. Hence, the effectiveness and durability of a water market depends on the degree of integration with existing rules and norms, such as the regulatory framework for water monitoring and enforcement, and the attitudes of farmers to the ownership and trade of water.

As the normative construct of Homo economicus is challenged as a basis for modeling human actors [12], attempts are being made to incorporate a heterogeneous set of real world, context specific behaviors into policy analysis. Researchers are discovering that the expression of individual preferences, especially in relation to public goods and environmental quality, may no longer be explained sufficiently by personal welfare [20, 21, 44]. Individual choice about public goods and environmental quality can be motivated also by prestige, public recognition, group belonging, avoidance of group sanction, and desire to contribute to the public good [5]).

This paper describes an ex-ante analysis of a potential water market for farmers in the Katherine region of the Northern Territory (NT), Australia who have licenses to extract prescribed allocations of groundwater from a specified section of an aquifer. This evaluation of the effectiveness of the water market arrangement in the context of existing social and institutional conditions and of heterogeneous behavior was undertaken to assist policy makers avoid institutional failures common to water management. There is a lack of data on the water trading behavior of farmers in northern Australia in water markets, and, as the behavior of individuals with non-market and social motivations may diverge substantially from theoretical predictions [12, 26, 28, 31, 43], this research deployed a synthetic methodological approach, combining field work, institutional analysis and experimental economics techniques to reveal this behavior in the local context and the responses of individual water users to different institutional arrangements combining different forms of communication and information. The observed bidding behaviors were used to calibrate the behavior of farmers as agents in an agent-based model in which a set of institutional arrangements were then simulated.

THE KATHERINE-DALY REGION

The Katherine-Daly River system is a set of tropical river sub-catchments in the monsoonal tropics of the NT (Fig. 1). It is home to approximately 14.070 people [13], is popular with local and international visitors, especially as a recreational fishing spot, supports pastoral and agricultural enterprises, and has significant social, cultural and conservation values [3, 18, 49]. There are two distinct seasons in the monsoonal tropics: a dry season from May to September almost without rain, and a wet season from November to March. Wet season rainfall accounts for over 90% of annual rainfall in the region [10]. Extensive underground aquifers are connected to the river system, ensuring relatively reliable flows of good quality water during the dry season. Average rainfall can be as low as 0.1 mm during the dry season [24]. This availability of year-round water and highly productive soils [1] underpin the consideration of further agricultural development in the region [17].

The ground and surface water of the Katherine-Daly system is allocated according to a prescribed set of multiple "beneficial uses" as defined in the Water Act 1992 (NT), including agriculture, public water supply and the environment. Agriculture is the largest user of water by a factor of approximately 4.5, accounting for 27.341 megaliters (ML) of a total 41.721ML extracted from the system annually [11]. Water extraction for agricultural use requires authorization under the Water Act 1992 (NT) through a license, except for stock and domestic purposes. Australia's national program of water reform, the National Water Initiative includes "the expansion of the trade in water" [8]. Water licenses in the NT can be traded in part or in full, temporarily or permanently where a Water Allocation Plan has been declared. The NT Government is considering the design of a water market for the region prior to a Water Allocation Plan being declared.

There are several conditions specific to the Katherine region that are being considered in the design of the water market:

(1) There is currently limited scientific understanding of how extraction from the groundwater source impacts on surface water flows, adding to the uncertainty surrounding the efficacy of instruments that seek to conjointly manage groundwater extraction and surface water flows.

(2) At the time of writing (August 2007), there were 18 recorded groundwater extraction licenses and approximately 60 applications awaiting consideration. (3) Field interviews with farmers have revealed prevailing attitudes to water property rights vested in the individual that suggest that a market based instrument alone may not be as effective at meeting the desired outcomes as would another approach [41].

This research was undertaken to provide insight into the second two of these aspects in support of designing an effective institutional arrangement for the management of water.

METHOD

While many water market analyses make use of general equilibrium models [29], this study applies a combination of field work, institutional analysis, experimental economics and agent-based modeling. The research was based on a collaborative partnership with departments of the NT Government, the NT Horticultural Association and the NT Agricultural Association. Semi-structured interviews were conducted with ten farmers, industry representatives and government agents about water use and management. The Institutional Analysis and Development Framework [27] was applied to clarify the links between national, territory and local rules about water (see Straton, Heckbert et al. 2006 for a report of the application of this framework). Techniques developed within experimental economics were employed using a subject pool of thirty-five self-selected participants in three water trading simulation workshops, and an agent-based model was built to simulate several policy scenarios. This paper focuses on the experimental economics and agent-based model.

Experimental Economics

The key methodological contribution of this research is in the use of experimental economics techniques to calibrate the agent-based model. We use a contextualized field approach according to the typology developed by G. Harrison and T. List [14]. Field experimental economics involves a controlled decision environment that has similar economic and biophysical features to a real world catchment and thus provides a formalized, replicable and relatively inexpensive method for assessing policy impacts prior to their implementation [9]. The analytical approach in these experimental settings enables a formal comparison of observed trading behavior of regional irrigators with theoretical predictions [47]).

Economic experiments were designed for two purposes: to test prior hypotheses about the impact of communication and information provision on the effectiveness of a water market in a tropical river setting in Australia; and to reveal the bidding behavior of north Australian farmers for water in a tropical savannas environment. Participants in the water trading simulation workshops were self-selected farmers from three local farming regions: Darwin rural, the Douglas-Daly and Katherine. Each was faced with a computer model of a hypothetical farm (based on existing farms in another region of Australia). All farms within one workshop group were located within the same catchment and extracted water from the same source. Twelve participants faced heterogeneous decision environments, enumerated as farm specific characteristics; including a water entitlement in megaliters (ML), marginal value of water, historic median rainfall in ML and their crop's water requirements. Workshop participants were asked to make monthly water use and water trading decisions within the context of a prescribed set of institutional arrangements for managing water use over the course of a year. These institutional arrangements included different combinations of the following: no water market; a water market, provision of real time data on how much aggregate water extraction differed from the environmental target of the experimental setting; a forum for discussion where voluntary contracts could be crafted; and provision of real time data on whether individual's actual decisions complied with the voluntary contract. Behavior was quantified as player income, market outcomes and environmental impact expressed as a socialized environmental levy [40].

To address the first purpose of the experiments, the effectiveness of different institutional arrangements was evaluated against the goals of minimizing environmental damage and maximizing farm income. Environmental damage was enumerated as the deviation of aggregate water extraction from natural flows. Maximizing individual income therefore was associated with attempts to reconcile minimizing the socialized environmental levy [see 40 for details]. Some key results are presented below [15, 37].

The experiments also revealed the bidding behavior of local farmers in a water market. The observed heterogeneous behavior of these farmers was used to calibrate the farmers as agents in an agent-based model (Heckbert, Smajgl et al., 2006; Smajgl and Heckbert, 2006).

The economic experiments enabled the testing of a set of hypotheses about the most effective institutional arrangement for the management of a common pool water resource in the NT. The arrangements tested involved a combination of a water market, levels of information provision, communication and voluntary contracting, and social sanctions. Outcomes are measured by: the environmental impact, which is measured by an environmental levy that all participants had to pay if their aggregate extraction did not match the environmental target; and the average farm income, measured by the average participant income. Participants in the simulation workshops were paid for their efforts based on their trader's income. This was calculated as an AUD$10 payment for attending, plus their farm income, which equaled the total of all monthly farm incomes, less the environmental levy for that year. Monthly farm income equaled total water usage times marginal value of water, less crop loss, plus income from the sale of water, less the cost of water bought. Farm incomes were translated into participant's incomes using a series of exchange rates to account for different farm sizes and characteristics [43].

Agent-Based Modelling

While many water market analyses make use of general equilibrium models (for example, [29]) and are based on optimal control theory, this analysis models the Katherine-Daly River system, mango farmers and policy-makers as a complex adaptive system [16] using agent-based modeling. Agent-based modeling was developed as a tool in ecosystem management through an interdisciplinary process that saw researchers attempt to reproduce the behaviors of heterogeneous agents involved in some shared situation. Bousquet and Le Page [4] find that such models are useful for problems where both social and spatial aspects are important.

Agent-based modeling can be used to analyze how different design options impact on some chosen outcomes of a water or emissions trading scheme, for example, where behavior is likely to be heterogeneous and spatially specific (see, for example, [2, 36]). In this case, the agent-based model is used to model: how behavioral rules of the individual farmers combine and interact to lead to some dynamics of the whole system; how different institutional arrangements impact on these dynamics; and how the adaptive behavior of farmers leads to irreversible structural changes in the system. In reporting the results, we focus on the second objective.

The "Tindall Aquifer Water Trading Model" [15], is an evidence based agent-based model that simulates farmers engaged in irrigated horticulture in and around Katherine and who extract from a specified section of an aquifer called the Tindall aquifer. Farmers in the model are assumed to all produce a mango crop (there was a lack of data for other crops produced in the area). The model is based on the last twenty-two years of rainfall data for the region, hydrological models of the Tindall aquifer [19, 33], actual property sizes and groundwater licenses that currently exist in the region, actual applications for further groundwater licenses, local mango production costs and prices [46] and a 20% cap on water extraction [22]. The model assumes that there is adequate enforcement of institutional arrangements. The model considers agents (acting as farmers) as the only buyers and sellers in the simulated water market.

Agents in the model decide how much water they will need in a month (based on published crop water requirements), and compare it to how much water entitlement they have on their water license in that month. Any difference is offered or sought in the local water market. Bids are based on individual farmer's marginal value for water and a mark-up, which represents how real world buyers and sellers deviate from their marginal value when making bids in a market. Marginal values are based on the difference between expected profit with and without required water entitlements. The mark-ups used in the model are based on the bidding behavior of participants in the experimental economics simulation workshops.

The water market is modeled as a double call auction market. All agents' water entitlements are adjusted to account for the outcomes of the water market and they then use the water on their mango crop. Profits are based on revenue from the sales of mangoes and water entitlements and the costs of water entitlements purchased, labor and other variable and semi-fixed costs. Profit is constrained by the availability of rainfall, water entitlements and labor.

The model also simulates farmers changing their farming strategy as a result of observing the strategies

Table 1. Treatments of institutional arrangements evaluated

Treatments	No information	Aggregate Information	Aggregate Information and Discussion	Aggregate Information, Discussion and Sanctions
No trade	1 field session	1 field session		1 field session
Closed call	1 field session	1 field session	1 field session	1 field session

Table 2. Mean environmental levy and mean participant income for each experimental treatment* (Straton, Heckbert et al., 2006)

	No Information, $		Aggregate Information, $		Aggregate Information and Discussion, $		Individual Information, Discussion and Sanctions, $		Mean, $	
	MEL**	MPI***	MEL	MPI	MEL	MPI	MEL	MPI	MEL	MPI
No tradin g	4.65	27.95	3.84	35.36	NA	NA	3.25	32.31	3.91	
Water tradin g	6.21	30.42	10.51	25.80	9.65	32.46	3.62	33.26	7.49	
Mean	5.43		7.17				3.44			

Note: [a] As only a single replicate of the field experiments was able to be undertaken, statistical analysis of the field experiments was not possible; [b] Mean environmental levy; [c] Mean participant income.

and profits of other farmers and running through whether those strategies would have improved their profit. The possible strategies include: (1) reallocating family labor from farming to other off-farm income generating activities; (2) increasing the number of hectares used for mango production; (3) selling water entitlements and ceasing farming to pursue off-farm income; and (4) changing water use by buying or selling water entitlements in the market. The simulation of farmer learning and adaptation in the model is based on fictitious play learning [48].

The institutional arrangements that were tested through the Tindall Aquifer Water Trading Model included the following: (1) the granting of an additional 41 licenses; and (2) the operation of a water market. This latter policy was an attempt to ensure the instrument matched the ecological features of the river system.

RESULTS

Evaluating the Effectiveness of Institutional Arrangements

An institutional arrangement with water trading alone had a negative impact on the environment, and did not impact on participant income. Compared to the no trading situations where the average environmental levy was $3.91, situations with water trading resulted in the average levy increasing to $7.49 (Table 1). There was little difference in average participant income when there was no trade compared to years when water trading was allowed.

Providing only aggregate information on extraction (a common practice) in combination with a water market is too crude to provide individual farmers with sufficient information to consider coordination possible. When combined with a water market, providing aggregate extraction information increased the environmental levy from 6.21 to $10.51, indicating that aggregate extractions were further from the environmental target than with no information, and decreased income from 30.42 to $25.80 (Table 1).

Allowing participants to communicate face-to-face about how much water they plan to extract allowed social contracts to form to minimize impact on the environment. This is indicated by the small decrease in the environmental levy (10.51 to $9.65) when discussion was combined with the provision of aggregate information. Combining face-to-face discussion with aggregate information led to higher levels of average traders' income in the market treatments ($32.46) compared to aggregate information without discussion ($25.80; Table 1).

Providing individual extraction information as a form of social sanctioning and providing opportunities for farmers to communicate further reinforced the social contract and minimized the environmental impact. The no trade situation was characterized by relatively constant levy values across the treatments. In the water trading situation, however, compared with aggregate information provision and discussion, the public disclosure of individual extractions combined with discussion substantially decreased the levy from $9.65 to $3.62, and increased average participant's income from 32.46 to $33.26 (Table 1).

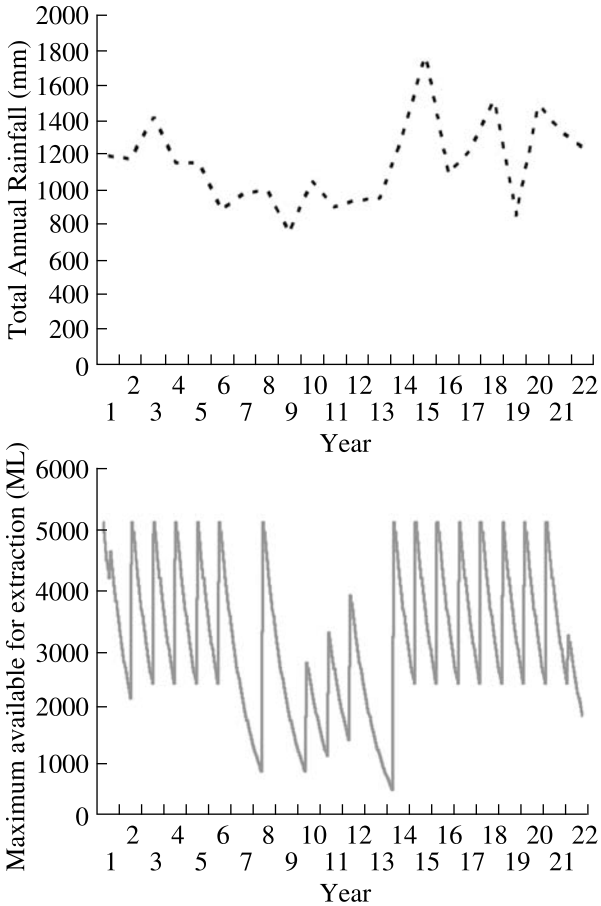

Fig. 2. Rainfall and maximum volume available for extraction for all simulations.

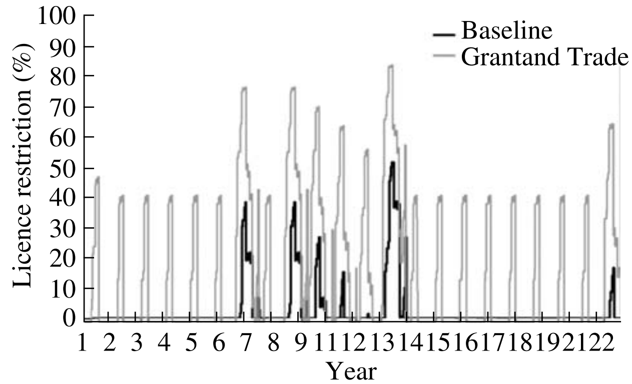

Fig. 3. Percentage by which licences will be restricted under the baseline and grant and trade scenarios (Straton, Heckbert et al., 2006).

The motivation for the individual information, discussion and sanctions treatments is not to enforce a penalty, but to encourage conformity to the environmental objective through social pressure arising from providing individual extraction information. The public provision of individual extraction information and a forum for discussion gave rise to verbal peer sanctions. Verbal peer sanctions invoked reputation to reinforce the social contract. This was tested further by observing the difference in the accordance with the social agreement in economic experiments conducting with students in a laboratory setting [43] and actual farmers from the NT in a real NT environment. This comparison revealed that the level of voluntary accordance observed between farmers involving the provision of information about individual extraction was substantially higher than that observed in the student sessions [45].

These results indicate that the public disclosure of individual extraction may be an important instrument in reducing the environmental impact resulting from irrigation activity when participants can both trade and communicate. The results are in accord with previous results [26]. This indicates that the social relationships between farmers in the Katherine region and their desire to maintain their reputation will impact on their adherence to a social contract. This is also reflected in the statement made in the interviews about the community ownership of water. These social relationships will be an important feature in managing water use in the NT.

Policy Scenarios

The Tindall Aquifer Water Trading Model enabled the testing of institutional arrangements for the management of a common pool water resource in the NT. The arrangements tested are the current arrangements, the granting of an additional 41 licenses and the operation of a water market. Outcomes are measured by: impact on total annual extraction, total mango profit, extent of pumping restrictions faced by farmers, the volume and value of water traded, and the adaptive behavior of farmers on observing their own and others' situations.

Total annual rainfall (mm) is the same for all scenarios. There is an initial period of abundant rain in years 1–6, followed by a number of dry years (approximately years 7 to 14) where rainfall levels do not sufficiently fill the aquifer. The maximum volume of water available for extraction for all scenarios is 20% of annual aquifer recharge. This volume increases and decreases with the wet and dry seasons of each year, and trends in line with rainfall (Fig. 2).

The baseline scenario simulates 18 licenses and no water trading. The second scenario simulates a situation where an additional 41 licenses have been granted and a water market is in operation (“grant and trade”). Extraction from the Tindall aquifer in the baseline scenario exceeds the maximum volume available for extraction in a few dry years in the middle of the 22-year simulation. Farmers in this baseline scenario would thus be required to limit their pumping by up to 50% of their entitlement in these years to ensure the

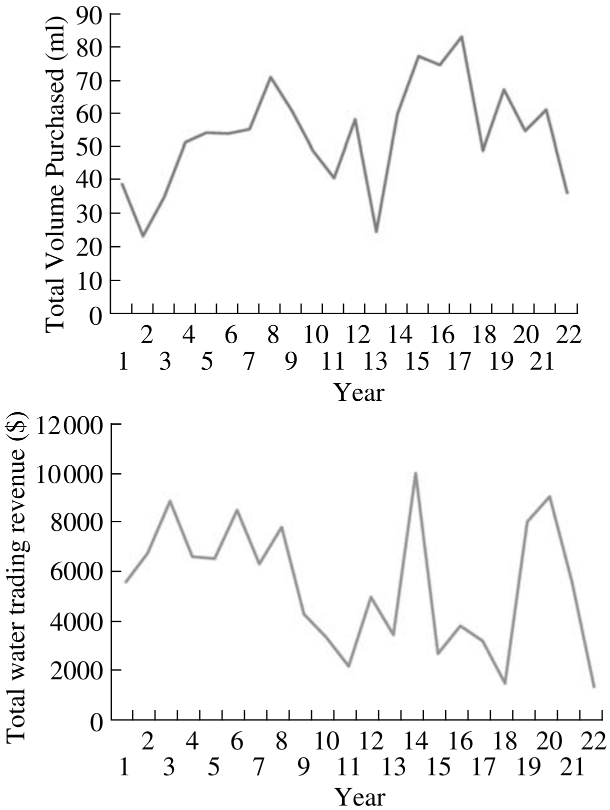

Fig. 4. Volume of water entitlements purchased and revenue from trading in water entitlements in grant and trade scenario.

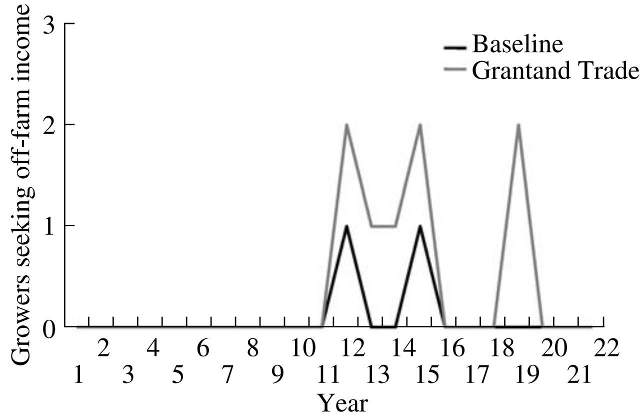

Fig. 5. Number of growers who seek off-farm income under the baseline and grant and trade scenarios.

20% on extraction is met (Fig. 3). Granting the additional 41 licenses and allowing water trading results in extraction that exceeds the cap in some months of every year. This translates to pumping restrictions for farmers in every year. Comparison of profit in this second scenario with a scenario where the new licenses are granted and water trading is not allowed reveal that while pumping restrictions may exert a downward influence on profit; this is offset to some degree by trading in the water market.

The total volume of water entitlements purchased never exceeds approximately 80ML, being less than 1% of the 14.122ML of groundwater from the Tindall aquifer used for agriculture in the region in 2004 (Faulks and Kirby 2004). Revenue from the sale of water entitlements ranges from less than $2.000 in year 18 up to approximately $10000 in year 14 (Fig. 4). In year 14, this equates to approximately less than 1 % of total profit from mango production.

The volume of water entitlements demanded, however, was significantly larger than the actual volume traded, reaching approximately 1.250ML in one year. This indicates that if supply matched this demand at the right price, the potential value of trading in water entitlements could be much higher. The reason why actual trade was much lower is that only one crop was simulated, suggesting that all farmers looking to purchase additional entitlements were looking at the same time.

An additional six farmers chose to exit the industry and seek off-farm income in the grant and trade scenario compared to the baseline (Fig. 5).

DISCUSSION

We now return to the issues raised by the two local conditions described at the beginning of the paper. The first issue relates to the fact that there are approximately 60 applications for water entitlements awaiting consideration by the NT Government Water Controller. The institutional arrangements simulated by the Tindall Aquifer Water Trading Model show that farmers will face pumping restrictions in some months of every year if all pending applications for water entitlements (41 at the time of the simulations) are granted. The water market is able to assist some farmers in managing the risk this presents to their profitability, however, the additional licenses and the water market will combine to result in a number of farmers choosing to exit the industry. The impacts that this change will have on the structure of the industry and on the local community are worthy of further examination.

The bidding behaviors observed in the water trading simulation workshops indicated that farmers are indeed heterogeneous in the motivation behind their bids for water entitlements. The fact that there were mark-ups, being the amount that their bids differed from their marginal values, reveals that their decisions were being guided by something other than personal welfare alone. This difference can also be explained in part by the face that participants were learning about the market.

The second issue concerns the fact that a market based instrument alone may not be as effective at meeting the desired outcomes as would another approach. Interviews with farmers reveal that there is resistance to the implementation of a water trading system in the NT, in part due to there being a lack of scientific knowledge and regulatory institutions to underpin a water market. The opinion was also expressed that the water belongs to "the community" and that individual farmers being able to profit from this community resource is not acceptable at present.

This finding is complemented by the economic experiments, which show that the social norms relating to social connections, reputation and reciprocity invoked by information provision, group discussion and peer sanctions are important features in improving the effectiveness of institutional arrangements for water management in the Katherine region of the NT. This suggests that an institutional arrangement be designed to incorporate these features.

The finding that both incomes and environmental quality can be improved with the provision of information about individual extraction and a forum for group discussion echoes that of other research. This includes findings that face-to-face communication is effective in helping social agreements to form and in reinforcing them, and that peer sanctions enabled through the provision of information about individual extraction can further reinforce cooperative strategies.

The synthetic approach taken for this research enabled the policy simulations to be based on realistic, heterogeneous behaviors, which also acted as an inbuilt mechanism for validation of this aspect of the model.

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