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Bargaining and Devolution in the Upper Guadiana Basin

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Bargaining and Devolution in the Upper Guadiana Basin

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Abstract

Increasingly, central governments approach contentious natural resource allocation problems by devolving partial decision-making responsibility to local stakeholders. This paper conceptualizes devolution as a three-stage process and uses a simulation model calibrated to real-world conditions to analyze devolution in Spain's Upper Guadiana Basin. The Spanish national government has proposed spending over a billion euros to reverse a 30 year decline in groundwater levels. We investigate how the government can most effectively allocate this money to improve water levels by utilizing its power to set the structure of a local negotiation process. Using a numerical Nash model of local bargaining, we find that if the national government creates appropriate incentives, local bargaining can produce water stabilization. The actual water levels that will emerge are highly dependent on the central government's decisions about the budget available to local stakeholders and the default policy, which. will be influenced by the relative value the government places on various financial and environmental outcomes. Our paper concludes by determining the relationship between these relative valuations and the government's preferences over water levels.

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1 Introduction

A common approach to resolving contentious local resource allocation problems is to empower local stakeholders to develop solutions that are specific to the local conditions. This approach is often referred to as devolution. Devolution appeals to central governments for a variety of reasons, including political philosophy, a belief that local interests better understand the problem details, and a desire to minimize implementation costs by encouraging local buy-in. Oates (1972) observed that the benefit or cost of decentralization relative to central control is largely determined by the degree of regional heterogeneity. Our interest in this paper is not whether devolution is an appropriate choice; rather, we note that, for better or worse, many national governments have chosen devolution to address certain issues. Our interest is in how the national government can ensure that the resulting outcomes achieve its goals. Our analysis is thus similar in character to the branch of the decentralization literature that focuses on developing mechanisms by which the central government can induce local governments to respect the national government's goal (see, for example, Levaggi 2002). Much of this literature focuses on a permanent assignment of responsibility for particular types of decisions to local governments. In contrast, our interest is in the one-time devolution of a particular real-world policy choice.

We conceptualize this type of one-time devolution as a three-stage process. The first stage is a **structure setting stage** in which a central government sets the structure for local bargaining. For instance, a familiar pattern in US environmental policy is that the national government sets an environmental threshold and threatens federally imposed regulations if individual states fail to meet the threshold. The threatened regulation provides a default outcome against which the state political process operates. It also creates a constraint on the options available at the local level; to avoid the default outcome, the state policy-making process can only consider policies that meet the threshold. The second stage is the **local bargaining stage** in which local stakeholders select policies within the structure determined in the previous stage. The last stage is the **implementation stage**, which determines how economic agents react to those policy choices. The first two stages are political economic problems, while the final stage is a purely economic problem. This three-stage framework is used to answer three questions. First, how does the outcome of the local bargaining process depend on the decisions made at the national level? Second, given that variation, what structure should the national government set in the first stage? Finally, what policy outcomes will result given the government's choices?

This paper applies our three-stage devolution framework to a groundwater allocation problem in Spain's Upper Guadiana Basin. Negotiations over groundwater issues have been studied in a variety of contexts. Netanyahu et al. (1998) apply both cooperative and non-cooperative bargaining models to groundwater allocation between Israel and Palestine. Just and Netanyahu (1998) investigate the divergence between "ideal" basin-wide management of multi-national river basins and the real world experience of bi-lateral agreements within these basins. A common theme of these papers is that the potential for free-riding and cheating may reduce the efficiency of final outcomes.

The setting we model differs from these papers in two key respects. First, our model considers a basin that lies entirely within one jurisdiction. We therefore model individual water users rather than aggregated states. As a result, we take free-riding behavior as given; farmers in our model respond optimally ex-post to whatever policies are imposed. Second, a major focus of our paper is the role of the national government in setting the conditions under which local negotiation occurs.

Over the last 30 years, the Upper Guadiana Basin has experienced large declines in groundwater levels. In recent years, the Spanish national government has indicated a willingness to appropriate significant funds to improve conditions in the Guadiana. It has also explicitly sought to involve local stakeholders in the process, seeking a compromise solution and ceding considerable control over the plan details to local entities. Yet, the local policy process has stalled and failed to produce a viable plan for improving water levels within the region.[1] We believe that this failure stems from the national government's failure to establish explicit consequences for local stakeholders failing to achieve compromise. By failing to do so, the national government

[1]In 2008, a plan was adopted. This plan is in the early stages of implementation and it remains to be seen whether it can ultimately be successful in stabilizing or improving water levels.

has established an implicit default — the continuation of current policies indefinitely. If the national government truly wishes to improve water levels, it must use both its budgetary powers and its power to set the default to meet its goals.

Water right enforcement is a central feature of the Guadiana problem. Although groundwater use in the region is legally allowed only with the possession of water rights, illegal use is rampant. Illegal use is facilitated by both the local political opposition to enforcement and the lack of infrastructure for monitoring water use. As a result, the Guadiana problem must be viewed through the lens of enforcement policy. There is a strong sense that effective enforcement is only feasible if local interests accept the rules regarding water use and that this acceptance is unlikely unless local interests feel that they were part of the plan development. This paper does not investigate whether local input is truly necessary. Instead, it demonstrates one way that the government might induce stakeholders to agree to a stringent enforcement policy. The approach draws on ideas developed in the voluntary compliance literature (Segerson and Miceli, 1998; Segerson and Wu, 2006). The basic lesson of this literature is that under certain circumstances, a government can convince firms to voluntarily comply with a goal by threatening an undesirable alternate policy. In the Guadiana setting, it is infeasible to induce voluntary compliance because of free-riding concerns. Instead, we demonstrate that with appropriate incentives, the national government can use the threat of a relatively mild fine policy to induce stakeholders to impose a much more

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stringent fine policy upon themselves as part of a local compromise solution.

Since it is difficult to precisely identify the national government's goal, we examine a stylized specification of choices facing the national government, focusing on the national government's tradeoff between the environment, farm profit, and the burden on taxpayers. We consider various possible levels for the government's willingness to trade between these objectives; for each level, we identify the government's optimal policy choices and the resulting outcomes.

In the next section, we describe the details of the Guadiana problem. We then develop a stylized model capturing the essential features of the problem. We describe the main results produced by this model and then offer concluding comments.

2 The Guadiana Basin

The Upper Guadiana Basin lies in the Castilla-La Mancha region of Spain. The area is heavily agricultural and relies on groundwater for most of its water needs. Over the last 30 years, groundwater has fueled significant economic growth in the region, but has also caused dramatic declines in water levels within the region. The declines have nearly destroyed the wetlands in *Las Tablas de Daimiel* national park, along with much of the other remaining wetlands in the region. Moreover, declining water levels have caused many existing wells to dry up. A number of authors and studies have described the history, economics, and social conditions within the Upper Guadiana (see *Rosell (2001)*,(Llamas and Martinez-Santos, 2005)). An approximate relationship between depth and use derived from (Bromley et al., 1996, 2001) suggests that if farmers continued current use indefinitely, water levels would fall from 50 m below surface today to 116 m below the surface in 30 years. A series of policy initiatives over the last 20 years have aimed to improve water levels, but have been unsuccessful at generating sustained reductions in use thus far.

There is a substantial literature on the economics of groundwater use. Economists have long argued that groundwater will be overexploited in the absence of coordinated management, since it is a common property resource. Early economic work on groundwater focused on determining the socially optimal groundwater extraction path and proposing regulatory instruments capable of achieving this optimum.[2] In 1980, Gisser and Sanchez demonstrated that the benefits of groundwater management can be small in practice. Koundouri (2004) presents a detailed survey of the economic literature on groundwater, including an extended discussion of papers that have investigated the robustness of the Gisser-Sanchez finding.

Three lessons from the groundwater literature are important for the Guadiana context. First, as pumping costs rise due to lower water tables, farmers will reduce their pumping activity. This feedback effect limits reductions in

[2]See, for example, Burt (1964, 1966, 1967, 1970); Bredehoeft and Young (1970); Brown and Deacon (1972); Gisser and Mercado (1973b,a); Brown (1974)

groundwater levels. Under the current common property regime, our economic model (described in the implementation section below) predicts that this feedback is likely to be mild; we project that farmers will cut back their water use from 677 Mm^3 per year today to an average annual extraction of 660 Mm^3, a reduction of barely 2.5%. Second, due to the pumping cost externality, farmers would collectively be willing to limit their use if barriers to collective action could be overcome. Our model suggests that if costless collective action were possible, farmers would reduce water use further to approximately 570 Mm^3, a reduction of approximately 15% from current levels. Finally, the Gisser-Sanchez results imply that the benefits of reducing the pumping externality are small, suggesting that overcoming the barriers to collective action is likely only if there are other externalities that whose resolution is also valued by the policy making process. In the Guadiana context, the second externality is the environmental impact on the wetlands. In the Guadiana basin, our simulations suggest that eliminating the pumping cost externality would increase farming profits by approximately 3% (see subsection 4.1), a value in line with many of the estimates in the literature.

A significant feature of the Guadiana problem is the importance of illegal water use. Legal use within the region is approximately 370 Mm^3, well below the estimated sustainable yield of 430 Mm^3 (Bromley et al., 1996, 2001). However, approximately 45% of all estimated water use is illegal.[3]

[3]All figures for illegal water use, and therefore for total water use, are estimates. See Appendix A.

Achieving reductions in water use therefore requires addressing the illegal use problem. There are two major impediments to reducing illegal use: insufficient infrastructure and political opposition. As shown in Section 4, with current monitoring technology, an enforcement regime capable of stabilizing water levels would be prohibitively expensive. An important component of proposed reforms for the region involves an investment in monitoring technology. In particular, attention is focused on installing meters on existing wells. Particularly for farmers with illegal wells, there is no incentive to install a meter unless the government provides a reward in return. Political opposition creates a second obstacle to effective enforcement. For historical reasons, the current distribution of water rights is widely viewed as unfair, fueling public outcry against attempts at enforcing water rights. Since one of the legal entities charged with enforcing rights is the local Water User Group, made up of farmers themselves, public opposition has thus far been sufficient to prevent enforcement.

The result is that addressing the concerns in the Guadiana basin requires both reorganizing and enforcing water rights. Following current discussions in the region, we model the reorganization of water rights through a combined program of purchasing some existing water rights and legalizing a portion of the water use on farms that currently lack any water rights. The key policy variables in the reorganization program are the budget available for acquisition of rights and the share of water use on farms without rights that will be legalized. The key policy variables in the enforcement program are the severity of fines and the funds made available for enforcement activities.

Given the prevalence of illegal use within the region today, it is critical that the two programs be coupled. Without enforcement, the purchase of existing water rights will not necessarily lead to actual reductions in water use; it may simply transform legal use into illegal use. To reinforce this coupling and to minimize enforcement expenditures, we assume that the government will link participation in either portion of the water right reorganization program with an agreement to install a meter.

Our model structure assumes that responsibility for setting these policies will be divided between the national government and a local negotiation process. We believe that the split described below is indicative of both political realities in the region and the decisions the national government appears willing to cede to stakeholders in the region. At the same time, we do not intend to imply that the national government is necessarily constrained by the split. If it had the political will to do so over the strenuous objections of citizens within the region, there is nothing that explicitly prevents the national government from directly setting all the policies. In the next section, we develop a stylized model of all three layers of decision making. Our model is designed to capture the key components of the debate at a high level. We thus focus exclusively on water use, abstracting away from quality issues.

3 The Model

In the first stage of our model, called the **structure setting stage**, the national government makes decisions that influence the structure of local bargaining. The decisions are represented by the vector $\mathbf{z}$. Once the bargaining structure is set, local stakeholders select the value of various policy instruments in the **local bargaining stage**. The policy choices are given by the vector $\mathbf{b}$. Finally, regional farmers respond to the policy instruments in the **implementation stage**. The choices of an individual farm are given by the vector $\mathbf{x}_i$; together these choices determine the value of an implementation vector $\mathbf{y}$, which includes both the farm choices and several other endogenous variables. Table 1 lists each of the variables that are endogenous to our model.

Our model includes four policy instruments, denoted by vector $\mathbf{g}$: the severity of fines for illegal water use (ϕ), the budget for monitoring water use (B_M), the budget for purchasing water rights from farmers (B_A) and the partial legalization of water rights on farms that currently lack any rights (λ). Responsibility for setting these instruments is divided between the national government and a local stakeholder negotiation process. Moreover, our model implicitly includes two policy vectors: one $\mathbf{g}_0$ is imposed if the stakeholders fail to reach agreement and the other $\mathbf{g}_N$ is the outcome of the bargaining process. In the structure setting stage, the national government makes decisions about how much to spend on enforcement and acquisition,

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Table 1: Endogenous Variables

Variable	Description
$\mathbf{g} = (B_M, B_A, \phi, \lambda)$	Policies selected during the first two stages
B_M	Annualized budget for enforcing water rights
B_A	Annualized budget for acquiring water rights
ϕ	Fine coefficient describin severity of penalties
λ	Legalized share of use on farms with no rights today
$\mathbf{z} = (z_M, z_A, z_\phi)$	Policies selected during the structure-settting stage
z_M	B_M available to stakeholders in negotiation stage
z_A	B_A available to stakeholders in negotiation stage
z_ϕ	Fine coefficient imposed if bargaining fails
$\mathbf{b} = (b_\phi, b_\lambda)$	Policies selected during the local bargaining stage
b_ϕ	Fine cofficient (ϕ) set during local bargaining
b_λ	Legalized share (λ) set during local bargaining
$\mathbf{x}_i = (\mathbf{L}_i, W_i^S, \sigma_i)$	Choices made by farm i
$\mathbf{L}_i$	Vector of land planted in each crop for farm i
W_i^S	Water rights sold by farm i
σ_i	Binary choice of whether farm i installs a meter
$\mathbf{y} = (\mathbf{L}, \mathbf{W^S}, H, \rho, p_W))$	All endogenous variables determined during implementation stage
$\mathbf{L}$	Vector of land use by crop for all farms
$\mathbf{W^S}$	Vector of water sales for all farms
H	Depth from ground surface to water level
ρ	Vector of probabilities that illegal use on each farm is detected
p_W	Price at which water rights are purchased

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as well as the severity of its "threat" to the local stakeholders. None of these policies is appropriate for inclusion in the local negotiation stage; national expenditures must be determined by the national government and only the national government can impose an enforcement policy outside of the local process. In the local stakeholder negotiation, we focus on two policies: the severity of negotiated illegal use sanctions and the negotiated portion of water use on farms that currently lack any rights should be legalized. The water acquisition and legalization policies are used as "carrots" to induce farmers to accept more stringent fines and agree to install water meters. As a result, farmers are only offered the opportunity to sell rights or receive a legalized share if they agree to install a meter.

Once the national government and local stakeholders have finalized negotiations, individual farmers must respond to the policies that have been agreed upon. Farmers thus play two roles in our model: in addition to participating in the local negotiation process, we require that they respond to the outcome of these negotiations in ways that are in accordance with their individual economic self-interests. Individuals farmers in our model choose how much acreage to plant in a variety of crops, how much water to sell, and whether to install a meter. Together, these choices also determine water use (and therefore water levels), the effectiveness of a given monitoring budget, and the price at which water rights are purchased.

In the remainder of this section, we describe the details of each stage of the model. Since the model must be solved using backwards induction, we describe the details of the stages in reverse order, beginning with the implementation stage, moving to the local negotiation stage, and finishing with the structure setting stage.

3.1 Implementation Stage

The first step in determining the impact of a policy vector $\mathbf{g}$ is determining the response of individual farmers. Individual farms within the model are indexed by i. We divide the farms into four types (small farms without water rights, small farms with water rights, medium farms and large farms) and let τ_i be the type for farmer i.[4] These types reflect the major divisions between farm types described in Appendix A.2. Each farmer chooses a vector of land allocated to each crop ($\mathbf{L}_i$), whether to install a meter (σ_i), and how much water to sell (W_i^S). Together, these choices are denoted by the vector $\mathbf{x}_i = \left(\mathbf{L}_i, W_i^S, \sigma_i\right)$. We assume that a fixed quantity of water is applied to a hectare of land for a given crop. The choice about how much water to use for farming thus follows directly from the choice of land allocation.

Our model of farm optimization is necessarily schematic; we assume that farmers plant the most profitable crop and abstract away other factors that might influence crop choice. Moreover, our model is static; we choose one crop allocation for the entire period. We are thus implicitly selecting long-run crop choice and therefore do not model costs of switching crops. The model may therefore overestimate farmers willingness to switch crops, particularly

[4] There are no medium or large farms in the region without water rights.

in the short run.

Farm revenue is given by

$$R(\mathbf{x}_i) = \sum_c (p_c \vartheta_c - \zeta_c L_{ic} - \xi_c) L_{ic} + p_W W_i^S \tag{1}$$

where c indexes crops, p_c is the market price, ϑ_c is the yield per hectare, L_{ic} is the hectares of land devoted to crop c , ζ_c and ξ_c are production function parameters, and p_W is the price at which water rights are purchased from farmers, determined endogenously by a budget balance condition. The first term is the revenue from selling crops and the second is the revenue from selling water rights.

Farm costs have three components: the cost of pumping water (C_W), meter installation costs (C_M) and expected fines for illegal use (C_F). The cost of pumping water is given by

$$C_W(\mathbf{x}_i) = eH\mathbf{w}^d \cdot \mathbf{L}_i$$

where $\mathbf{w}^d$ is a vector of irrigation doses per hectare for different crops, e is the energy cost per meter of pumping lift, and H is the pumping lift in meters. Meter installation cost are

$$C_M(\mathbf{x}_i) = m\sigma_i$$

where m is the cost of a meter.

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Expected fines for illegal water use are given by

$$C_F\left(\mathbf{x}_i\right) = \rho_i \phi \Psi\left(\mathbf{L}_i, W_i^S\right)^{\gamma}$$

where ρ_i is the probability of detection, ϕ is the coefficient describing the severity of sanctions, $\Psi\left(\cdot\right)$ is illegal water use, and γ determines how rapidly per unit fines increase with illegal water use.,Illegal water use is a residual amount given by

$$\Psi\left(\mathbf{x}_i\right) = \max\left\{\mathbf{w}^d \cdot \mathbf{L}_i + W_i^S - W_i^R, 0\right\} \tag{2}$$

where $W_i^R\left(\lambda\right)$ denotes the farmer's water rights before water sales as function of the legalization policy determined in the bargaining stage. For the three types with water rights, W_i^R is independent of the bargaining; for the final type (small farms without rights), their endogenous water rights are given by

$$W_i^R\left(\lambda\right) = \lambda \sigma_i W_i^0 \tag{3}$$

where W_i^0 gives the farm's current water use. Since $\sigma_i = 0$ unless a farmer has installed a meter, farms without rights today will not get a legalized share unless they install a meter.

We assume that $\gamma > 1$, implying that the per unit fine rate increases as illegal water use increases. This approach is motivated by two factors. First, farmers' behavior must respond smoothly to changes in fine policy to use standard optimization techniques, which is guaranteed by this form. Second, farmers in the region have expressed a preference for an increasing fine structure (Lopez-Gunn, 2003, pp. 243-244). The coefficient gives the fine paid by a farmer caught using one unit of water illegally.

Of course, farmers only pay a fine if they are ***caught*** using water illegally. Monitoring farmers is costly and the budget for enforcement is set by the national government. The cost of monitoring an individual farmer depends on the current monitoring technology.[5] As more farmers install meters on their wells, a given expenditure on monitoring leads to higher detection rates. As a result, the probability of catching illegal users is endogenous to the farm production problem. The probability that an individual farmer is caught if using illegal water is given by

$$\rho_i = \frac{N_m \nu_m + N_{nm} \nu_{nm}}{B_M} \cdot \left(\sigma_i \omega_m + (1 - \sigma_i)\, \omega_{nm}\right) \tag{4}$$

where N_m is the number of farms with meters, ν_m is the cost of monitoring a farm with a meter, N_{nm} and ν_{nm} are the equivalent for a farm without a meter, and ω_m and ω_{nm} are the probabilities that illegal use is detected if monitoring occurs for farms with and without meters, respectively.[6] The revenues from fines are returned to the taxpayers as described in subsection

[5]Today, monitoring in the Guadiana basin can be done by remote sensing (which is problematic for small farms), by validating production plans, by physically visiting farms, or by monitoring electricity usage. Discussions in the region about improving monitoring are highly focused on the installation of meters rather than expanding other approaches.

[6]We do not vary the allocation of monitoring effort between farms with and without meters. This policy choice would be interesting to investigate in future work.

3.3.

Farmers have diminishing marginal utility, giving an optimization problem of

$$\max_{\mathbf{x}_i} F\left(\mathbf{x}_i\right) = \left[R\left(\mathbf{x}_i\right) - C_W\left(\mathbf{x}_i\right) - C_M\left(\mathbf{x}_i\right) - C_F\left(\mathbf{x}_i\right)\right]^{\eta} \tag{5}$$

for some $\eta < 1$, subject to

$$W_i^S \leq W_i^R \cdot \sigma_i \tag{6}$$

$$\sum_c L_{ic} \leq \bar{L}_i \tag{7}$$

where $\bar{L}_i$ is the total land available to the farmer. The first constraint states that farmers cannot sell more water rights than they currently have and cannot sell any water rights unless a meter is installed. The second constraint states that a farmer cannot plant more land than he has.

The collective impact of farmers must be determined by jointly solving all the individual first-order conditions and the budget balance condition

$$B_A = \sum_i p_W W_i^S. \tag{8}$$

To do so, we compute the first-order conditions for a representative farmer from each type.[7] The full solution to the implementation stage jointly solves

[7]See the appendix for a description of the optimization technique used to address the discrete choice of whether or not to install a meter.

the farmers' first-order conditions for each farm's choices ($\mathbf{x}_i$), its detection probability (ρ_i), pumping lift (H), and the price of water (p_W) given the policy vector ($\mathbf{g}$). There is no closed-form solution to this system of non-linear inequalities; its solution is denoted $\mathbf{y}^*(\mathbf{g})$.

Three specific outcomes of the implementation stage play an important role in the two policy-setting stages. The resulting water level is given by

$$W^L(\mathbf{y}) = H_0 - H\left(\sum_i \mathbf{w}^d \cdot \mathbf{L}_i\right) \tag{9}$$

where H_0 is a baseline from which pump lifts are calculated and $H(\cdot)$ is a function relating total water use to pumping depth. Moreover, the total profit of each group of farmers is given by

$$\pi_t(\mathbf{y}) = \sum_{i:\tau_i=t} \left[R(\mathbf{x}_i) - C(\mathbf{x}_i)\right] \tag{10}$$

where t indexes the four farm types. Finally, total fine revenues are

$$\varphi(\mathbf{y}) = \sum_i \rho_i \phi \Psi\left(\mathbf{L}_i, W_i^S\right)^\gamma \tag{11}$$

3.2 Local Bargaining Stage

Today, water policy decisions in the Guadiana Basin are being made through a stakeholder negotiation process. In our model, this process is responsible for setting two components of $\mathbf{g}$: the negotiated fine (b_ϕ) and the negotiated legalized share (b_λ). Even in the negotiated solution, the remaining two components of $\mathbf{g}$ are set by the national government. The bargained policy vector $\mathbf{g}_N$ is thus given by

$$\mathbf{g}_N(\mathbf{b}, \mathbf{z}) = (z_M, z_A, b_\phi, b_\lambda). \tag{12}$$

Based on our review of the policy discussions, we identify five major stakeholder groups: environmentalists, and four types of farmers, distinguished by size and water rights. Each of the groups is represented at the local bargaining table by a single player. These players are indexed by j. For the four farm groups, $j = t$ and the player's utility functions is given by

$$U_j(\mathbf{g}_N(\mathbf{b}, \mathbf{z})) = \pi_j(\mathbf{y}^*(\mathbf{g}_N))^{\delta_j} \tag{13}$$

where δ_j is the level of risk aversion for the stakeholder group representing that farm type. The environmental stakeholder group is represented by a player with the utility function

$$U_j(\mathbf{g}_N(\mathbf{b}, \mathbf{z})) = W^L(\mathbf{y}^*(\mathbf{g}_N))^{\delta_j}. \tag{14}$$

The outcome of the local stakeholder negotiated process is highly influenced by the stakeholders beliefs about what they believe will happen if they fail to reach agreement, i.e. by the vector $\mathbf{g}_0$. We assume that national government makes a three-pronged threat to the local stakeholders: refusing to

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legalize any water use, imposing a penalty for illegal use, and using all its allocated funds for monitoring. This implies that

$$\mathbf{g}_0 = \left(z_M + z_A, 0, z_\phi\ , 0\right). \tag{15}$$

The bargaining process is modeled using the bargaining solution developed by Nash (1950) extended to multiple players (Lensberg, 1988). In our setting, the Nash bargaining solution is given by

$$\max_{\mathbf{b}} \prod_{\mathrm{j=1}}^{\mathrm{J}} \left[U_j\left(\mathbf{g}_N\left(\mathbf{b}, \mathbf{z}\right)\right) - U_j\left(\mathbf{g}_0\left(\mathbf{z}\right)\right)\right]^{\frac{1}{J}}.$$

where j indexes the stakeholder groups. The solution to this problem is found using numerical techniques and is given $\mathbf{b}^*\left(\mathbf{z}\right)$. Similarly, we call the resulting negotiated policy $\mathbf{g}_N^*\left(\mathbf{z}\right)$.

3.3 Structure Setting Stage

We assume that the national government seeks to balance three objectives: (1) maximizing total farm profits, (2) improving water levels, and (3) minimizing government expenditures. Total farm profits are

$$\Pi\left(\mathbf{z}\right) = NPV\left[\sum \pi_t\left(\mathbf{y}^*\left(\mathbf{g}_N^*\left(\mathbf{z}\right)\right)\right)\right] \tag{16}$$

and the total government expenditure is

$$TC(\mathbf{z}) = NPV\left[z_M + z_A - \varphi\left(\mathbf{y}^*\left(\mathbf{g}_N^*(\mathbf{z})\right)\right)\right]. \tag{17}$$

This yields a government objective function of:

$$\Omega(\mathbf{z}) = \Pi(\mathbf{z}) + \alpha_e W^L\left(\mathbf{y}^*\left(\mathbf{g}_N^*(\mathbf{z})\right)\right) - TC(\mathbf{z}) - \alpha_t TC(\mathbf{z}) \tag{18}$$

where α_e gives the marginal value the government places on water level improvements and α_t is a coefficient governing the deadweight loss of taxation. Specifically, α_e is the government's marginal willingness to trade reductions in annual farming profits for increases in water levels, measured in € /m . Its value is influenced by both the political power of environmental lobbies and individuals' willingness to pay for water level improvements. Absent contingent valuation studies for the Guadiana problem, we have no basis for selecting a particular value of α_e. Accordingly, we consider a range of values from 0 to 100 million euros. We vary the value of α_t from 0 to 0.1.

If there were a closed form representation of $\mathbf{y}^*\left(\mathbf{g}_N^*(\mathbf{z})\right)$, maximizing Eq. (18) would be straightforward. Instead, generating each point in the mapping requires solving the numerical model. Solving this model for a single combination can take several hours. It is thus impractical to attempt a direct solution of the government's optimization problem using the full numerical model. To surmount this difficulty and save computation time, we solve the full model for a grid of possible values of $\mathbf{z}$. Our results presented in subsection 4.4 were generated by selecting the point in this grid that yielded the highest value of Ω rather than the optimizing over the full model. The results should therefore be interpreted as providing a rough estimate of the policy choice that would be selected by the government.

4 Results

We use the numerical model developed in Section 3 to produce four types of results. First, we compute the land use choices that would maximize an equally weighted utilitarian social welfare function by allowing a benevolent dictator to directly select land use for each farm type. Since land use choices implicitly determine water use, this corresponds to allowing the benevolent dictator to set water use. We compute these estimates for several different marginal values of water level improvements. These computations provide an estimate of the efficient level of water use. Second, we explore the prospects for improving water levels using enforcement policy alone. Third, we use the bargaining model to assess whether the carrot-stick framework described in Section 3.1 can induce significant improvements in water levels. Finally, we combine the full three-stage model to address the national government's choices in the structure setting stage.

4.1 Efficient Water Levels

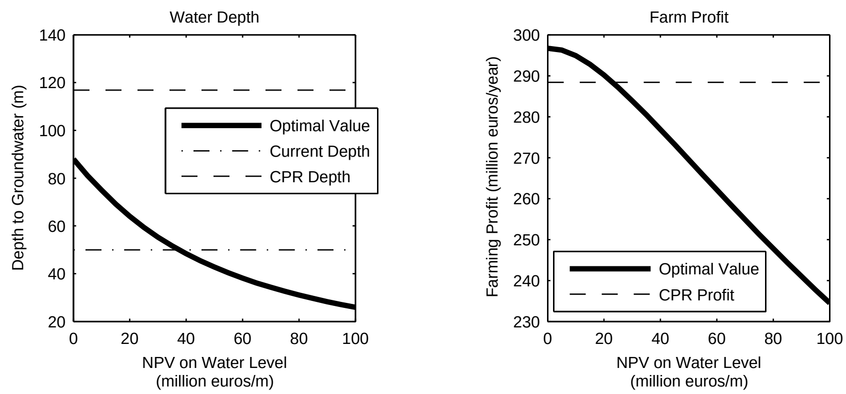
The two panels in Figure 1 illustrate the impact of eliminating both the pumping and environmental externalities related to water use. The size of the environmental externality is dependent on the monetary value of the wetlands. We have considered a range of possible monetary values for the wetlands from 0 to 100 million € per meter. Each point in the diagrams represents the internalization of both externalities for a specific value placed on the wetlands. The points are found by setting all the policy instruments and water sales to zero and solving

$$\max_{\mathbf{x}_i} \sum_i \pi\left(\mathbf{x}_i\right) + \alpha_e W^L\left(\mathbf{x}_i\right)$$

for various values of α_e.

When $\alpha_e = 0$, the impact on the wetlands has no cost to society and the only externality is the pumping cost externality. This calculation corresponds to maximizing farm profits and thus illustrates the impact of eliminating the pumping cost externality alone. Elimination of the pumping cost externality would reduce pumping lifts by approximately 30m and increase farm profits by just over 8 million € per year, an increase of just under 3%. As the value on the wetlands increases, the monetary size of the damages imposed by the environmental externality increases. At the extreme right, the marginal value of environmental water level improvements is set at a net present value of 100 million euros of farm profits per meter of water level improvement

Figure 1: Utilitarian Social Welfare Maximizing Outcomes

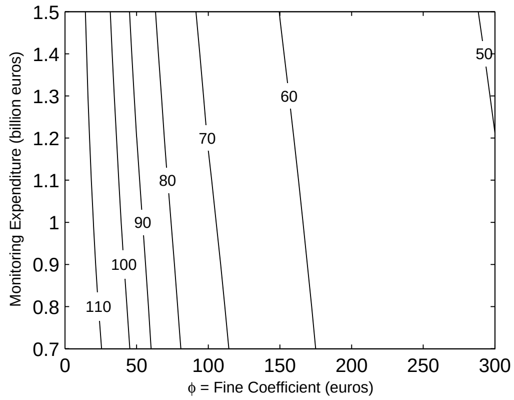


(equivalent to roughly 3 million € in annual farm profits). In each diagram, the consistently dashed line shows the projected outcome under the current common property regime, assuming no policy changes occur. Finally, the line with alternating dashes and dots in the middle of the water depth diagram illustrates the current water depth. This diagram suggests that if costless enforcement were possible, the utilitarian social welfare maximizing policy would be consistent with water level stabilization if the marginal value of water level improvements just under 40 million € per meter of improvement.

4.2 Enforcement Policy Alone

Since individual farmers will always have an incentive to free-ride, the first-best outcomes in Figure 1 are unattainable. Some enforcement mechanism must be used to induce farmers to reduce water levels. Figure 2 shows the resulting water depths for different combinations of the fine coefficient (ϕ) and monitoring expenditures (B_M). The value of the fine coefficient gives

Figure 2: Water Depths Resulting from Unilateral Enforcement Policy (m)



the fine that would be paid by a farmer caught using 1000 cubic meters (m^3) of water illegally.[8] The labels on each contour give the depth to groundwater in meters. The results are consistent with expectations: water depths fall (that is, water levels rise) as either the fine coefficient or the monitoring expenditure increases. At the extreme left, when fines are zero, the size of the monitoring budget has no impact – water depths remain at the common property level of approximately 116m. Fines are quite effective at reducing pumping depths small amounts, but improvements in water depths need increasingly high fines as depths fall.

Under the special plan for the Guadiana basin, the Spanish government has indicated a willingness to spend approximately 1 billion € to address the region's water problems. Our model predicts that with this budget, the government would have to set the fine coefficient at around 300 € to stabilize

[8]Note that according to the fine structure specified in Section 3, the fine coefficient is measured in units of € per (thousand m^3)$^\gamma$. For simplicity, we simply refer to € .

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water levels at current depths using enforcement policy alone.

The results suggest that it would be *possible* to reduce water use through enforcement policy alone. Yet, this approach will disproportionally impact small farmers without rights. From an implementation perspective, this is potentially problematic in that it is likely to give rise to political opposition. Indeed, such political opposition has been at the heart of the failures of government efforts to address the Guadiana problems in the past.

4.3 Bargaining Solution

In this subsection, we focus on the second stage of the model, taking outcomes of the first stage as given. First, we describe the bargaining outcome for a given default policy in detail. We then vary the level of the default fine coefficient (z_ϕ) and assess how this influences the bargaining. In this section, we freeze the monitoring and acquisition budgets at net present values of 100 million and 900 million € , respectively. These numbers were chosen to be representative of current plans to spend over 1 billion € with the vast majority targeted for a water rights acquisition plan.

We use a default fine coefficient of 100 € for the base simulations. Bargaining against this default, stakeholders agree upon a fine coefficient of roughly 6000 € and a legalized share of approximately 43% of existing use on farms without rights. This negotiated fine coefficient corresponds to an average fine per thousand m^3 of 1750 € for the farms caught using illegal water. This is a high fine, particularly in relation to current pumping costs of 70

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€ /thousandm^3 and farming profits of approximately 1200 € per thousand m^3 of water use. In other words, with this fine level, illegal water costs over 25 times as much as legal water *if the illegal use is detected.* Yet only a small number of farms get caught using water illegally, so the average *expected* fine is only 172 € /thousand m^3. This implies that the expected cost of illegal water is nearly three and a half times the expected cost of legal water. As we would expect, these high fines are effective at deterring illegal water use; no farm group averages more than 0.45 thousand m^3 of illegal water per farm in the equilibrium. What is striking about these high fines is that farmer groups agree to impose these fines *upon themselves* in exchange for the government's carrots: diverting a significant portion of its budget away from enforcement toward acquiring water rights and allowing stakeholders to reallocate some of those rights to farms without water rights today. This result is discussed in more detail below.

In this base scenario, the government purchases 100 Mm^3 of water rights and grants approximately 115 Mm^3 of new rights, increasing the amount of legal water use approximately 15 Mm^3. Yet the dramatic increase in enforcement means that total water use falls from 680 Mm^3 to just under 400 Mm^3.As a result, water levels recover nearly 8 m from current levels. In contrast, if the default fine coefficient of 100 € were imposed in isolation, water levels would fall just over 20 m from their current level. Negotiation thus increases the water level roughly 30 m relative to the default policy. Moreover, the resulting water levels are nearly 70 m higher than the projected

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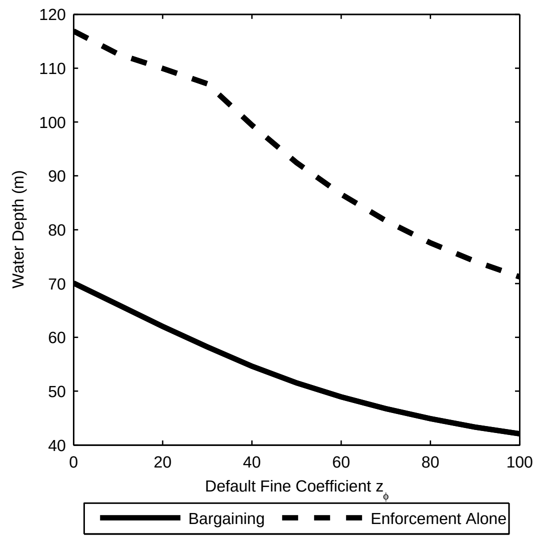
Figure 3: Equilibrium Water Depth as a Function of Default Enforcement



level resulting from continuing current policies.

To assess the sensitivity of this result with respect to z_ϕ, we solved the local negotiation stage under a variety of default fine specifications. Figure 3 shows the impact of these fine scenarios. As expected, the final water depth decreases (and water level rises) as z_ϕ rises. A default fine coefficient of approximately 50 € is sufficiently high to stabilize water levels given the currently announced budget. This default induces a bargaining solution with a final fine coefficient of approximately 6000 € and legalization of roughly 60% of the usage on farms without rights today. For comparison purposes, we have included a second line showing the water depths resulting from enforcement policy alone.[9]

[9]This line traces the value of water depths along the horizontal line located at 1 billion € in Figure 2.

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As in our base case example, local stakeholders choose a very stringent fine policy in each of these solutions. Through the negotiation, farmers agree to impose upon themselves enforcement regimes that have been seen as infeasible in the region thus far. They do this because the incentives offered by the national government in the form of legalized water rights and water right purchases outweigh the costs of having their water use effectively regulated. It is critical to the success of the policy that farmers are indeed willing to impose a larger fine coefficient through negotiation than the national government threatens.

To understand this result, recall that the objective in the Nash bargaining model is to maximize the product of players' gains relative to the default over the set of Pareto improvements on the default. The maximum will clearly occur at a point where all players experience a gain (assuming such a point exists). Therefore, a bargaining solution requires increased profits for every farm group **and** lower water use to increase the payoff of environmentalists. The only way to increase the payoff of environmentalists is to ensure that water levels are higher in the bargained solution than in the default. The only way to substantially improve the payoff of farmers without rights is to offer them a legalized share. Yet, doing so increases their incentive to use water since these farmers now pay fines on a smaller portion of their use. Unless the stakeholders can generate enough water use savings from farms with rights, they must increase enforcement to consider a positive legalized share in the solution.

The acquisition process increases the payoffs of farmers by offering them payments for a portion of their water rights. In principle, this lowers water use by inducing farmers to switch production from high water use crops to low water use crops. However, unless there is effective enforcement, farmers may sell their water rights but continue to use most of the water they sold. Their legal use will go down, but illegal use will increase leaving little change in overall use. Therefore, without effective enforcement, there may not be funds to purchase enough rights to generate significant decreases in water use.

Fortunately, the model predicts that the incentives offered are sufficient to induce farmers to accept more stringent enforcement than the default policy.[10] There are two important drivers of this result. First, the monitoring cost saving achieved by a combination of meter installation and high fines allow a large financial transfer to farmers with rights in the form of water right purchases. Second, the water savings from the acquisition allow granting small farms considerable rights to use water while still reducing overall water use. As a result, all parties gain relative to the default. However, it is important to realize that at the currently announced budgets, significant water levels improvements will not occur unless the central government can credibly threaten to impose a default fine unilaterally should stakeholders fail to reach agreement.

[10]Note that this is a general result of the model. For any default enforcement policy, the stakeholders will agree to a more stringent policy in the negotiated solution.

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4.4 Structure Setting

Our final set of results illustrates how the government might set policies in the structure setting stage. As discussed in subsection 3.3, it is not feasible to optimize Eq. 18 using the numerical simulation model. Instead, we solved the local bargaining model for various values of $\mathbf{z}$.[11] We then computed the value of $\Omega(\mathbf{z})$ assuming various values for α_e (the marginal value of water level improvements) and α_t (a parameter describing how quickly the deadweight loss of taxation increases). Finally, we selected the point in our grid of $\mathbf{z}$ values that yielded the highest value of Ω. Regardless of the value of α_e or α_t, the highest values of Ω were always associated with the lowest non-zero value of z_M included in our policy grid. This result is not surprising; it is consistent with the general observation that the most cost effective monitoring regimes set extremely high fines and engage in very little monitoring. It is important to note, however, that the policies in which $z_M = 0$ were never associated with the highest value of Ω.

Figure 4 shows the selected values of z_ϕ and z_A as a function of α_e.[12] When $\alpha_e = 0$, the national government cares only about farming profit and government expenditures. When $\alpha_e = 75$ at the extreme right, the national

[11] Our policy grid analysis had two steps. First, we varied z_ϕ from 10 to 100, total expenditure $(z_M + z_A)$ from 0.7 to 1.5 billion € , and the share spent on acquisition from 0.8 to 0.94. Based on the results in this hypercube, we then analyzed a grid of policies in which we froze z_M at 1.25 million € per year (roughly 43 million in NPV) and varied z_ϕ from 0 to 100 € and z_A from 0.5 to 1.5 billion € . Finally, we included the outcome of continued common property access to groundwater in our set of options available to the government.

[12] In all cases, z_M was set equal to 2 million € per year, which corresponds to a net present value of 42 million € .

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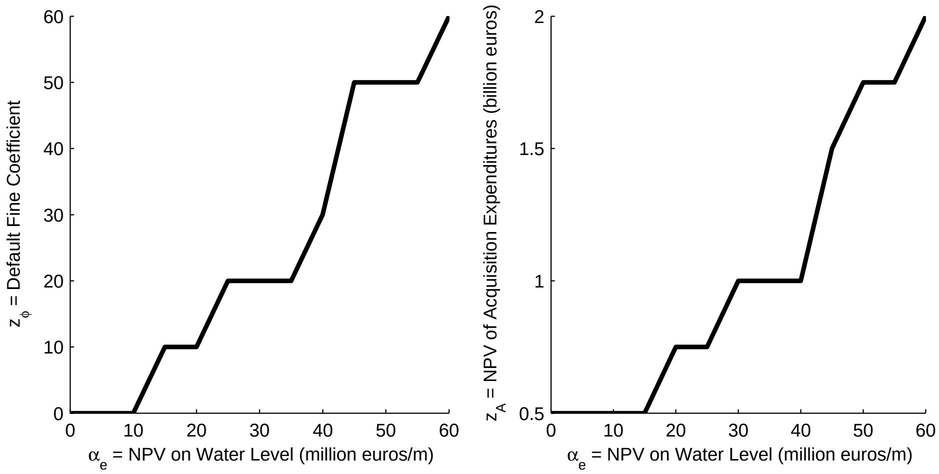
Figure 4: Policy Choices for Various Political Weights

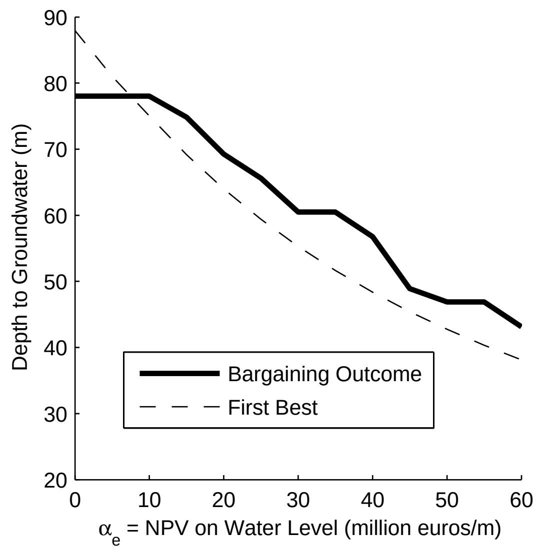


government is willing to spend 75 million € in net present value per meter of water level improvement. In the diagram, we set the value of α_t at 0.1. Increasing or decreasing the value of α_t has the expected impact (increases will lead to smaller expenditures and higher depths while decreases lead to larger expenditures and smaller depths.

When the environmental value of water level improvements is low, the government will spend very little money and not threaten fines. The specific budget of 500 million € identified in the diagram for the very lowest values of α_e was the smallest budget in our grid. The government might well reduce the budget below this amount, but it will choose some action over inaction due to the pumping cost externality. This is apparent because the identified policy was chosen over doing nothing.

As the environmental value of water level improvements increases, both acquisition budgets and default fine coefficients increase. Figure 5 graphs the

Figure 5: Water Depth Associated with α_e



resulting water depths in a similar plot. The dashed line in the water depth diagram is the line from 1 showing the utilitarian social welfare maximizing outcome with costless enforcement and the same marginal value of water level improvements. At the extreme left of the plot, the devolution process described in this paper will reduce water levels ***more*** than the first-best, despite the cost of enforcement. This result is driven by the presence of an environmental stakeholder insisting on water level improvements in the local negotiation. Although granting power to the local process means that water use may be cut too much, this result is still preferred by the national government to continuing to allow unrestricted common property access to the groundwater. As the weight on water level improvements increases, the corresponding depths fall. A marginal value of roughly 45 million euros per

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meter of water level improvements would lead the government to adopt a policy that could be expected to induce water level stabilization.

5 Concluding Remarks

The numerical simulations in this paper generate several conclusions. First, our analysis of enforcement policy confirms that it is unlikely that enforcement policy alone can successfully solve the Guadiana problem. Simulations suggest that even with extremely high penalties for those caught using illegal water, the government would still be required to spend a prohibitively large sum on monitoring in order to stabilize water levels at the current levels. Moreover, this policy would place all of the burden of water reduction on farms that have no legal rights. These farms are predominantly small, family-owned operations and policy-makers are reluctant to destroy their profitability. Moreover, there is no evidence that the national government has the political will to unilaterally impose an unpopular enforcement policy over the strong objections of those within the region.

Successful water use reduction requires coupling enforcement policy with a water rights reorganization program. If farmers agree to install meters and accept higher fines, the cost of an effective enforcement regime can be substantially reduced. Two possible incentives to promote meter installation are the opportunity to sell water rights and a partial legalization of current use. Our simulations indicate that if the national government combines sufficient funding for these incentives with sufficiently strong threats if agreement is not reached, then a local stakeholder bargaining process can stabilize water levels or even reverse the current declining trend in water levels. For instance, using a total budget of 1 billion €, the national government would be required to use a fine coefficient of well over 300 € to stabilize water levels if it used enforcement policy alone. In contrast, by threatening a fine coefficient of merely 50 €, the government can induce a bargaining solution that stabilizes water levels for the same overall budget. The incentives are sufficient to induce farmers to install meters and to accept increased fines. As a result, substantial monitoring savings are achieved. The savings can then be used to fund the incentive programs.

Many of the basic features of the model analyzed in this paper, including the conflict between agricultural and environmental uses and the problem of enforcement, are common to many environmental problems. Increasingly, devolution is being adopted as the policy of choice for addressing many such conflicts. Our analysis highlights the important connections between choices about the structure of devolution and the ultimate bargaining outcomes. In the Guadiana example, decisions made at the national level determine whether the local stakeholder process can be effective. If the national government fails to establish a strong credible threat, the local bargaining will produce minimal gains in water levels, if any. In contrast, with appropriate incentives, the local stakeholders ***can*** achieve substantial improvements in water levels. Moreover, these results demonstrate that by offering incentives, a national government can induce local stakeholders to adopt an effective enforcement regime themselves. This level of involvement may foster local buy-in and reduce political opposition to enforcement.

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A Appendix

This appendix provides additional details on several elements of the model.

A.1 Implementation Stage Computations

Subsection 3.1 describes the equations that implicitly define $\mathbf{y}^*(\mathbf{g})$. Solving this system numerically presents a number of challenges. In this section, we describe our solution method, beginning with the first-order conditions for individual farms.

The first-order conditions for land use and water sales are found by simply taking derivatives. However, the decision to install a meter is a binary choice, so calculus techniques are inapplicable. Accordingly, we use calculus to solve two problems, one assuming no meter installation ($\sigma_i = 0$) and one assuming a meter is installed ($\sigma_i = 1$). The optimized payoff in the two cases is written $F_i^*(0)$ and $F_i^*(1)$. Pure profit maximization dictates that farmers should install meters whenever $F_i^*(0)$ exceeds $F_i^*(1)$. If farmers behaved this way, however, our model would be discontinuous whenever $F_i^*(0) = F_i^*(1)$. To preserve continuity we "smooth out" the installation choice by assuming that different farmers incur different non-pecuniary net benefits from installing meters. Specifically, we assume that the non-pecuniary utility gain from installing a meter is a random variable denoted by θ. θ is distributed throughout the population according to a cumulative distribution function given by $K(\theta)$. We assume this distribution is constant for all farm types. A farmer installs a meter if $\theta_i > F_i^*(0) - F_i^*(1)$. Since all farms of the same type are identical except for θ_i, the fraction of farms of type t installing a meter is given by $K(F^*_{i|\tau_i=t}(0) - F^*_{i|\tau_i=t}(1))$. Clearly, this fraction increases as the difference $F_i^*(0) - F_i^*(1)$ decreases. The variable θ can be interpreted in a variety of ways: some farmers are likely to be reluctant to install meters, either for ideological reasons or because they mistrust promises made by the government in return; other farmers may be more civic-minded and more willing to install meters to help promote responsible groundwater use.

Changes in groundwater levels occur over time. To capture this variation, it would be necessary to incorporate a full dynamic optimization model. However, doing so would also exponentially increase the complexity of the analysis and provide little extra intuition. This model therefore adopts a static analysis, but ensures that data are consistent with respect to annual versus lump sum values and the comparison of impacts realized at different times. To do so, all lump sum payments in the model are converted into annualized values. Conversions are made using a real interest rate of 5%.

The Bromley *et al* paper predicts the level of groundwater 30 years from today. We approximate the time path of decline with a linear model and calculate implied pumping costs for each year. We then calculate a constant annual pumping cost that generates an equivalent net present value cost. Farmers make their (constant) annual decisions on the basis of this cost. In reality, water levels would decline more rapidly in early years and then slowly level out. The linear choice is simpler and also offsets the consequences of failing to vary water extractions over time.

The full model developed in Section 4.3 can only be solved using numerical solution techniques. The numerical analysis uses MATLAB's Newton-Raphson based optimization algorithms. As noted in Section 3.2, the solution to the implementation stage is the joint solution to all farmers' Kuhn-Tucker conditions. These conditions form a system of nonlinear *in*equalities, which causes two numerical difficulties. First, the system is difficult to solve.[13] Second, the solution to the inner system is inherently non-smooth at the boundaries of the constraint surface. As a policy instrument changes slightly, the equilibrium may move from a region where one of the inner inequalities is binding to one where it is not. This can create a kinked or discontinuous response, which is problematic for numerical optimization methods.

Both problems are addressed by converting the inner constrained problem into a nearly equivalent unconstrained problem using penalty functions. For example, instead of explicitly preventing farmers from exceeding their current farm size, a large penalty is subtracted from the payoff if farmers violate their land use constraint. The penalty function approach is frequently used in the operations research literature (Pinar, 1996; Ç. Pinar and Zenios, 1994). Several other features of the basic model create non-smooth responses. Each of these are addressed by approximating the non-smooth functions with smoothed ones.

A.2 Data description

The main crops in the region are vineyards, cereals, horticultural products (primarily melons, garlic, and onions), and corn. Small farms grow almost

[13] There is a substantial literature on the difficulty of finding numerical solutions for complex Nash equilibrium games of this form. See Krawczyk (2005); Krawczyk and Uryasev (2000) for a review of past approaches to the problem and a numerical solution technique.

Table 2: Net Revenue and Water Requirements of Regional Crops

Crop	Average Net Revenue (Pre-Water Costs) (€ /ha)	Average Irrigation Dose (m^3/ha)	Average Revenue per m^3 (€ /m^3)
Vineyards	704	1,500	0.563
Horticultural Products	2,780	4,500	0.401
Cereals	419	2,800	0.242
Corn	1,506	7,500	0.143

Data in this table are estimates. See Appendix A.

exclusively vineyard and horticultural products, while medium farms grow a mix of vineyards, horticultural products, and cereals. Large farms grow very little vineyard or horticultural products, preferring cereals and corn. Corn is a particularly water intensive crop grown exclusively on large farms. Horticultural products are considered socially desirable as they promote employment in the region. However, they are also relatively water intensive. Table 2 shows the average net revenue and water requirements for each of these crops.

Observed farming patterns are drawn from Llamas and Martinez-Santos (2005), Confederacion Hydrografica del Guadiana (2007), and Llamas et al. (2006). Farm production functions are calibrated using positive mathematical programming (Howitt, 1995). Bromley et al. (1996, 2001) construct a hydrological model of the Guadiana basin and project water levels under various water use levels. They provide several data points, from which we construct an approximate relationship between water use and groundwater levels (Figure 6). Continuation of current water use (approx 675 Mm^3) will result in a substantial drop in water levels. Stabilizing levels requires substantial cutbacks. Stabilization is marked on the figure. There are several model parameters for which information is limited or imprecise, including illegal water use and monitoring costs. However, policy discussion is currently proceeding with information similar to that used here.

We combined information from a variety of sources to parametrize our model. Availability of information on water use in the basin is limited. This appendix describes our assumptions and our efforts to reconcile information across sources.

Estimates of the total number of farms in the region varied from 20,000

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Figure 6: Projected Groundwater Depth at Various Use Levels

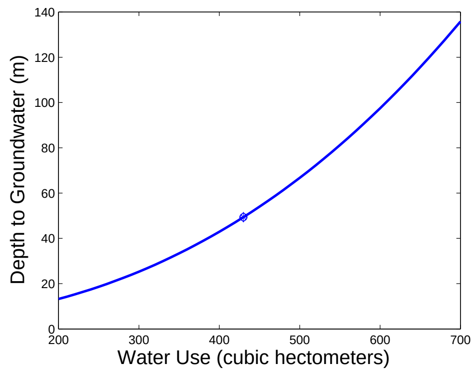

Table 3: Farmers with water rights

Farm size category	Farm size (ha)	Representative size (ha)	% Farms with rights	Number of farms with rights	Legal irrigated surface
Small	0-10 (48%) 10-20 (32%)	7.2	80%	5,600	40,320
Medium	20-50	35	14%	980	34,300
Large	50-250	150	6%	420	63,000
Total			100%	7,000	137,620

Note: Total number of farms with rights = 7,000

to approximately 33,000 farms. Our analysis assumes that there are 25,000 farms. According to PEAG, there are approximately 7,000 exploitations or legally irrigated farms in the region. Of these, 48% are between 0 and 10ha, 32% are between 10 and 20ha, 14% are between 20 and 50 ha, and 6% between 50 and 250 ha. We combined these farms into three size categories as shown in the table below. The total irrigated acreage derived from these calculations is very close to the total legal irrigated acreage reported in Llamas and Martinez-Santos (2005).

The remaining farms in the region are assumed to have no water rights. Subtracting the 7,000 legal farms from 25,000 total farms leaves us with 18,000 farms without legal water rights. We assumed these farms are all small farms with the same representative size as small legal farms. This

Table 4: Legal irrigated surface, irrigation does and water use by crop type

Crop type	Legal irrigated surface (ha)	Irrigation dose (m^3)	Water use (m^3)
Winter cereals	62,000	2,800	173,600,000
Horticulture	24,000	4,500	108,000,000
Maize	9,000	7,500	67,500,000
Vineyards	45,000	1,500	67,500,000
Tot/Avg	140,000	4,075	416,600,000

gives us a total acreage of farms without rights of 7.2 ha times 18,000 farms or approximately 129,600 ha. Adding this acreage to the total from Table 1, we have a total irrigated acreage of approximately 267,000 ha. This number is close to but a little higher than estimates of the total irrigated surface (230,000ha) from remote sensing (Llamas and Martinez-Santos, 2005; Confederacion Hydrografica del Guadiana, 2007).

According to SIAR estimates (Llamas and Martinez-Santos, 2005), the legal irrigated surface is distributed across crop types as shown in table 2. According to previous studies on the production system of the basin, we distinguish three main production regimes: small farms producing vineyards and horticultural products, medium farms producing vineyards, horticultural products and winter cereals, and large farms producing winter cereals and maize.

Because maize is grown only by large farms, all 9,000 ha of maize production occurs on large farms. This implies that approximately 14% of the 63,000 ha irrigated by large farms is devoted to maize production. We therefore assume that 14% of the acreage on a representative large farm (or 21 ha) is devoted to growing maize. The remaining 86% (129 ha) is devoted to winter cereals.

All together, the large farms devote approximately 54,000 ha to the production of cereals. This implies that the remaining 8,000 ha of cereals must be produced by medium farms. This accounts for approximately 24% of the total medium farm acreage. According to Tarjuelo (2007), about 30% of the irrigated land of a medium farm is devoted to vineyards. For an individual medium farm, this implies that approximately 10.5 ha are devoted to vineyards. Therefore, the irrigated surface that medium farms devote to vineyards is about 10,290 ha. Finally, the remaining 46% (16,010 ha) of medium farm land is devoted to horticultural crop production.

Table 5: Farm Size and Water Use

	Small Farms w/ Rights	Small Farms w/o Rights	Medium Farms	Large Farms
Number of Farms	5,600	18,000	980	420
Average Size (ha)	7.2	7.2	15	150
% of Area	16	52	6	25
% of Water Use	12	40	16	32
% of Water Rights	20	0	27	53
Avg. Legal Use Per Farm (thous. m^3)	13.5	0	100	467
Avg. Illegal Use Per Farm (thous. m^3)	1.5	15	11.2	51.9

Small farms with legal rights produce vineyards and horticultural products. Since the total irrigated surface devoted to horticulture is 24,000 ha and medium farms devote 16,010 ha to horticulture, small farms must devote 7990 ha to horticulture. Using similar logic, small farms devote 34,710 ha to vineyards. This corresponds to approximately 1.4 ha of horticulture and 5.8 ha of vines for our representative small farms.

We assume that the small farms without water rights are similar in structure and crop choice to those with rights. This implies an additional 25,200 ha of horticulture using approximately 113.4 Mm^3 of water and 104,400 ha of vines using approximately 156.6 Mm^3 of water. All together, total water use on farms with no rights totals approximately 270 Mm^3. From Table 4, water use on farms with rights totals approximately 417 Mm^3, generating total water use in the region of approximately 687 Mm^3, which is close to the CHG estimates of the water use in agriculture within the region (685 Mm^3). We have very little direct information on the allocation of precise water rights among the farms with rights. The analysis in this paper was performed assuming that 10% of the water used by a representative farm with rights is in excess of the authorized amount, regardless of farm size. Combined, this information produces the distribution of land and water use by farm type shown in Table 5. It demonstrates that large farms control a disproportionate amount of the water rights and produce more water intensive crops than their smaller neighbors.

Data on crop returns vary widely. Table 8 reports values averaged from several sources (CHG, FAO-Stat, Juan et al. 1999). These values were used to calibrate production functions using the technique described in Howitt (1995).

Table 6: Crop Returns

	Horticulture	Corn	Irrigated Cereals	Irrigated Vines
Quantity (kg/ha)	35000	10760	3500	7600
Price (€ /kg)	0.122	0.16	0.18	0.19
Gross return (€ /ha)	4270	1722	630	1444
Water costs (€ /ha)	315	525	196	105
Non-water costs (€ /ha)	2380	975	215	490
Amortization (€ /ha)	85	6	8	109
Total costs (€ /ha)	2780	1506	419	704
Net return (€ /ha)	1490	216	211	740
Subsidies (€ /ha)	0	330	270	0
Net return with subsidies (€ /ha)	1,490	546	481	740

Assumes a water cost of 0.07€ $/m^3$.