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## Abstract

This paper tests the contribution of institutions to the promotion of cooperative behavior, taking seriously the endogeneity of the institutions themselves. Theft of water by manipulation of water meters is an important constraint on the implementation of economic pricing policies, particularly in semi-arid regions of the developing world. We show how cooperative management institutions can reduce theft, improving incentives for efficient water use, by inducing peer monitoring by cooperative members. We show in a theoretical model that theft is more likely when prices are high, punishments weak, cooperatives large and the uptake of water-saving technologies low. However, cooperative membership, punishment levels and technology adoption are not exogenous but are chosen by cooperative members in response to conditions that themselves influence incentives for theft. We test the model on data from Tunisia, relying on instruments that proxy for unobservable monitoring costs to deal with the endogeneity of these proximate determinants of theft. The results provide strong confirmation of the ability of well-designed incentives to reduce theft, as well as of the tendency of individuals to adapt their behavior to the level of monitoring costs. Higher monitoring costs have a positive direct effect on the incidence of theft, and a further positive indirect effect by weakening the incentive for farmers to adopt water-saving technologies. But various features of the design of institutions can counteract these effects.



## ملخص

تفحص هذه الورقة مدي إسهام المؤسسات في دعم السلوك التعاوني مع مراعاة تأثير المتغيرات الداخلية للمؤسسات نفسها. إن سرقة الماء بالتلاعب في عدادات المياه هي قيد مهم يعوق تنفيذ سياسات التسعير الاقتصادية خاصة في المناطق شبه الجافة من الدول النامية. بينا كيف تستطيع مؤسسات الإدارة التعاونية التقليل من السرقة و تنمية الحوافزللاستخدام الفعال للمياه وذلك من خلال الحث علي مراقبة النظراء من قبل الأعضاء التعاونيين. وبينا في نموذج نظري أن السرقة يزيد إحتمال حدوثها عند ارتفاع الأسعار وضعف العقوبات وضخامة التعاونييات مع تدني مستوي تقنيات الحفاظ علي المياه. ومع ذلك من ذللك فإن العضوية بالتعاونيات ومستويات العقوبة وتبني التقنيات لا تتم بتأثير عوامل خارجية بل يقدرها أعضاء التعاونيات إستجابة لشروط التي تؤثر علي حوافزالسرقة. وإختبرنا هذا النموذج بإستخدام بيانات من دولة تونس معتمدين علي أدوات لمراقبة غير ملحوظة للتكاليف للتعامل مع تأثير الجوانب الداخلية لتلك العوامل الدافعة. وركزت النتائج علي قدرة الحوافزإذا أجيد تصميمها علي تقليل حالات السرقة وكذا أنها حثت الأفراد علي تكييف سلوكهم مع مستوي مراقبة التكاليف. ولإرتفاع تكاليف المراقبة مزيد من التأثيرات الإيجابية المباشرة علي حدوث السرقة وكذا تأثيرات إيجابية غير مباشرة بإضعاف دوافع الزراعيين إلي تبني تقنيات للحفاظ علي الماء غير أن هذه التأثيرات من الممكن مواجهتها عن طريق ما يتضمنه تصميم المؤسسات من سمات متنوعة.

## 1. Introduction

Economic behavior is influenced not only by formal incentives but also by institutions, which can be understood as informal systems of rules, enforced by a variety of explicit or implicit means. However, institutions themselves evolve in part because of their incentive properties — certain institutions are more suited for some economic environments than others. For instance, many institutions are formed in response to a perceived collective action problem, which the effective design of such institutions can help to alleviate, though rarely without some cost. In this paper we look at the influence of institutions on a serious problem that arises in water management, namely the problem of water theft. The growing scarcity of fresh water in many parts of the world has led to an urgent search for solutions, including the adoption of economic pricing policies to encourage conservation[1] . But it is becoming apparent that when farmers are in a position to steal water, typically by manipulating water meters, not only may economic pricing policies fail to encourage conservation, but they may even increase the incidence of theft itself. In the presence of theft, optimal pricing rules need to be adjusted and prices will typically be lower than in its absence: it is worth tolerating some allocative inefficiency in water use in return for a lower incidence of theft.

Theft does not take place in an institutional vacuum; indeed, different types of water management institutions may create more or less favorable conditions for theft to flourish. In particular, it is well known that cooperative institutions may be well suited to deal with a number of collective action problems that arise in relation to water management, though their success in doing so depends on some quite precise features of their design[2] . In this paper we show that such institutions may also be well suited to dealing with theft; we discuss the features of their design that enable them to do so using both theory and empirical evidence. We show that the incidence of theft varies considerably in response to these features and discuss implications for policy. We consider in particular the properties of cooperative water users' associations whose members are subject to joint responsibility for aggregate quantities of water used, and show that this feature is likely to induce peer monitoring by cooperative members, which is a more efficient means of reducing theft than any available to more centralized management structures[3] .

Many government authorities are reluctant to acknowledge the severity of the problem of water theft, and it is frequently claimed that the authorities' inability to recover costs of water supply from users is due to purely technical difficulties such as leakages from the water supply network. Two kinds of evidence from our own research make us think this is an implausible explanation: first, and on an anecdotal level, many farmers can be observed using water in ways that seem inconsistent with their facing full economic prices (placing rotating sprays at the corners of fields where only a quarter of the emitted water falls on the land being irrigated, for example). Secondly, the econometric analysis we perform below indicates that amounts of water unrecovered from users vary in response to factors such as prices that are consistent with their being caused by theft; we are reluctant to believe that water pipes respond to economic incentives in the same way that human beings do.

Testing hypotheses about the determinants of theft is a major empirical challenge, since many of the features of the institutional environment that are empirically associated with incentives

[1] See Johansson (2002) for a review.

[2] See Wade (1987), an early contribution to what is now a large literature.

[3] There is now a substantial literature on peer monitoring. See Stiglitz (1990), Besley & Coate (1995), Armanderiz de Aghion (1999), Ghatak & Guinnane (1999), Che (2002), and Conning (2005).

for theft are not exogenous features of the environment, but evolve in response to environmental characteristics that themselves influence theft, and may even evolve in direct response to perceived theft levels[4] . Our procedure is to use theory to focus attention on the underlying determinants of both institutional structure and (together with institutional structure) of individual behavior. The theory then guides our search for proxies for unobserved variables, and instruments for observed but endogenous variables, that enable us to identify the appropriate causal relationships in our data, which come from an original survey conducted by one of us in Tunisia. We find that a variable that plausibly proxies for monitoring costs can influence theft, in the sense that higher monitoring costs make theft easier. We also find that the incidence of theft is affected by aspects of the institutions — the rules specifying how severely individual members will be punished for theft, and the overall number of members in the cooperative, which influences the scope for free-riding. However, measuring this relationship requires us in turn to see how various constraints affect the way in which these institutions evolve. Once we have accounted for the potential endogeneity of institutional characteristics, we find support, as predicted, for the hypotheses that larger cooperatives entail more theft, and higher ones reduce theft. Also, a higher price of water is associated with greater adoption of water-saving technologies, and in turn a higher expected incidence of theft reduces the incentives for adoption. Nevertheless, other economic, socioeconomic, physical and geographical factors seem to be relevant for the design of cooperatives and farmers' decisions, and some of these factors are considered in the empirical analysis.

The paper is structured as follows. Section 2 sets out our model. We state a number of propositions describing the dependence of theft on a number of determinants, some of which are themselves determined by more fundamental factors including costs of monitoring. We use these propositions to make predictions that can be tested empirically. Section 3 describes our data and Section 4 tests the empirical predictions and reports results. Section 5 concludes.

## 2. The Model

Consider two identical risk-neutral farmers who produce a homogeneous farm good using water as an input. The yield (y) response to water (q) can be described by the relation y = g (q) ; where g (:) is an increasing and strictly concave function. The cost incurred by each farmer for using water, measured in units of output, is c per unit of water. In addition the farmer pays a linear price t per unit of water used, a price which is determined by the Water Authority (hereafter WA). The pro…t-maximizing quantity of water equates the marginal value product of water to the marginal cost of generating such a quantity

$$g0 (q) = c + t \quad (1)$$

In the absence of asymmetric information, and abstracting from any shadow cost of public funds that might imply Ramsey-pricing considerations, the WA will wish to set $t$ equal to $\gamma$, which represents the full public cost of resource provision, including O&M costs, investment costs, extraction externalities associated with pumping from a shared aquifer and any shadow cost associated with the scarcity of water.

However, when the individual farmer's water use is her private information (unlike the total amount of water use by farmers which is observable to the WA), the farmer who is equipped with an individual water meter can send a report of the amount used, denoted by $q^r$, that may

[4] A paper by Asim (2001) argues that the influence of social capital on the performance of infrastructure projects has been overrated because different designs of projects can onset the impact of adverse social capital. Without wishing to take a stance on the relative importance of social capital and project design as explanations for different performance, our results support the idea that improved design of the structure and rules of projects (and related institutions) may compensate for otherwise adverse conditions.

differ from the true quantity. We write the amount of water stolen as $a = q\ q^r$. The response of the WA will differ according to whether there is centralized or cooperative management[5] ; we consider these two cases in turn.

### *2.1 Centralized Management*

We assume that under centralized management the WA can commit, before farmers choose their actual and reported levels of water use, to a level m of monitoring its members' activities, at a cost $\psi$ (m), which is increasing and convex[6] . We assume that monitoring cannot be conditioned on the farmer's report and must be the same for all reports. The probability that a farmer is discovered stealing is given by

$$P(m; a) = \min [\kappa m \max \{a, 0\}, 1] \quad (2)$$

where $\kappa > 0$ (we assume henceforth that it is sufficiently small to generate an interior solution)[7]. When the farmer is detected stealing, her true intake is established without error and she pays $tq^r$ plus a penalty[8] proportional to the amount of water stolen, $F^{cs}$. It is the nature of the monitoring system which makes it possible to use a punishment device based on individual levels of theft. The punishment is measured in terms of the length of time for which water is cut off from a cheating member. This length is proportional to the farmer's level of theft. The punishment is assumed to take the form:

$$F^{cs} = f \max \{a,0\} \quad (3)$$

where the punishment rate f is positive, greater[9] than t, and given outside the model[10] . There are no rewards for over-reporting.

The order of events is that the WA sets m and t, then, each farmer chooses the quantity of water to use $q^{cs}$ and the report to file $q^{rcs}$. In what follows we focus on the sub-game perfect equilibrium and solve the model by backward induction. In stage 2 of the game, the farmer chooses $q^{cs}$ and $q^{rcs}$ in order to maximize her expected payoff, i.e.,

$$\max_{(q;qr)} U^{cs}(q; q^r) = g(q)-cq-tq^r-\kappa mf(q-q^r)^2$$

[5] Since the total amount of water use by farmers is publicly known, this makes it like a moral hazard in teams and solutions other than cooperatives would be possible (see Holmostrom, 1982).

[6] The cost of monitoring should be understood as including not only the wages of monitors, but other costs as measurement devices aiming at making water intakes observable.

[7] One could think that the probability as it is written $\rho = \kappa m \alpha$ could be greater than or equal to 1 if monitoring is high enough. This cannot be the case for the following reasons: Firstly, in the centralized structure monitoring the behavior of each farmer apart is very costly, especially when the number of farmers operating in the irrigated area is large (for instance in Tunisia, government agencies manage public irrigated areas with more than four hundred farmers); this essentially implies that monitoring cannot be high enough (otherwise, the WA could prevent theft completely). Secondly, the maximum amount of water the farmer can steal is equal to her true water intake, namely $\alpha = q$; which is not high enough because we implicitly assume a constraint availability of water (there is an increased scarcity of fresh water in many parts of the world and especially for the agricultural sector). So we can always choose a parameter $\kappa$ sufficiently small to ensure that $\kappa qm < 1$, and then $\kappa\alpha\ m < 1$, which can be set as the probability of catching a farmer stealing.

[8] The subscript "cs" is to indicate the centralized structure by contrast to "c" which will be used for cooperatives.

[9] Because otherwise the farmer will always have an interest in stealing everything. The net return of water theft is equal to $(t-\kappa mfa)$ a; with the probability $\kappa m\alpha < 1$: If $f < t$; one gets $\kappa m\alpha f < f < t$, and therefore theft is strictly beneficial; this essentially implies that the net return is maximized when the farmer is stealing everything. We are not here concerned with the optimal choice of f since our focus is on cooperative management.

[10] We are not here concerned with the optimal choice of f since our focus is on cooperative management.

Whose first-order conditions with respect to q and $q^r$ are respectively given by

$q^{cs}$: g' (qcs) = c + 2 κm*f* ($q^{cs}$-$q^{rcs}$), (4)

and

$q^{rcs}$ : t = 2 κm*f* ($q^{cs}$-$q^{rcs}$) (5)

Eq. (4) into Eq. (3) implies that the amount of water used by the farmer is independent of the levels of monitoring and punishment.

g' ($q^{cs}$) = c + t (6)

Now let us turn to the initial contracting stage, where the WA anticipates the farmer's behavior and picks *m* and *t* that maximize the social benefit. Specifically this benefit function is the sum of the farmers' surplus, 2[g ($q^{cs}$)-(c + γ) $q^{cs}$ - κm*f* ($q^{cs}$-$q^{rcs}$)$^{2]}$ and the water supplier surplus which is equal to the revenue from water proceeds, 2t$q_r$; from which is deduced the cost of water provision to the irrigated area, 2q; and the cost incurred by monitoring, 2 ψ (m)

$W^{cs}$ (m; t) = 2[g ($q^{cs}$) - (c + γ) $q^{cs}$ - κm*f* ($q^{cs}$ - $q^{rcs}$)$^2$ –ψ' (m)] (7)

We can then show:

PROPOSITION 1: The optimal monitoring and pricing policy used by the WA {$m^{cs}$; $t^{cs}$} satisfies:

$$m^{cs} : \frac{(t^{cs})^2}{4\kappa (m^{cs})^2 f} = \psi'(m^{cs}) \tag{8}$$

$$t^{cs} = \gamma \left[ \frac{2\kappa m^{cs} f}{2\kappa m^{cs} f - g''(q^{cs})} \right] \tag{9}$$

and yields a level of theft by each farmer given by

$$a^{cs} = \frac{t}{2\kappa f m^{cs}} \tag{10}$$

**See the appendix for the proof.**

The proposition says that some monitoring is always required in equilibrium. However, because monitoring is costly, the optimal response of the WA is to tolerate some theft in order to save monitoring costs. Moreover, in the presence of theft, the optimal second-best price of water is typically lower[11] than in its absence, i.e., tcs < $\gamma$ it is worth tolerating some allocative inefficiency in water use in return for a reduction of theft occurrence.

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[11] Setting the equilibrium price of water below its first-best level, γ does not unambiguously imply that providing water is a money losing-enterprise. The explanation of it is as follows: The full-information social welfare function is equal to the sum of the farmers' surplus 2 [g (q)- (c + t) q] and the water supplier surplus equal to the revenue from water proceeds, 2tq; from which is deduced the cost of water provision to the irrigated area, 2 γ q

$$W^{FB}(q) = 2[g(q) - (c+\gamma)q]$$

When theft occurs the social welfare is given by Eq. (7). Note that the occurrence of theft causes a departure from the full-information social welfare by the term $2[\kappa m f (q - q^r)^2 + \psi(m)]$ which can be interpreted as the efficiency cost of theft or the social lcost of theft.

An increase in the price of water increases both the efficiency gains from water use (defined as $2[g(q) - (c+\gamma)q])$ by $\frac{\partial\{2[g(q)-(c+\gamma)q]\}}{\partial t} = 2[g'(q) - (c+\gamma)]\frac{\partial q}{\partial t} = 2(t-\gamma)\frac{1}{g''(q)} > 0$

### *2.2 Cooperative Management*

We assume that the total amount of water used by the two cooperative members, $Q = q_1 + q_2$, is publicly known free of charge, and can thereby serve as a basis for aggregate payments from the cooperative to the WA. In particular, this allows for a joint-liability rule: if theft occurs the cooperative as a whole receives a punishment proportional to the total amount of water stolen (which is publicly observable):

$$F^c = f\left(\sum_{i=1,2} q^i - \sum_{i=1,2} q_r^i\right) \qquad (11)$$

Now suppose that, relative to the WA, farmers have a comparative advantage in monitoring each other, as a result of geographical proximity and/or long-standing trade links. We assume that peer monitoring brings about only evidence of the occurrence of theft but not of its amount. The WA may then contemplate the possibility of inducing peer monitoring between the two farmers, typically through the establishment of a cooperative governed by rules that make all group members jointly liable. If theft occurs in the cooperative, the fine is shared equally between farmers who are caught stealing; otherwise it is shared by all members.

Peer-monitoring incurs a private cost $\psi$(m) to a farmer, assumed to be increasing and convex. Each member commits to a level of monitoring[12] (observable by other members) before actual and reported water uses are decided. The probability that a farmer $i$ is caught stealing is then given by:

$$P_i(m_j, a_i) = \kappa m_j \max\{a_i, 0\} \qquad (12)$$

and is thus increasing in the farmer's theft level and the monitoring level of the other. Farmers do not collude in either their monitoring or their production decisions[13]. The order of events is therefore that the WA fixes t and f, then individual members choose $m_i$, then having observed each others' choice of monitoring they choose $q_i$ and $q_i^r$. The outcome will depend on the severity of the punishment rate. If it is sufficiently high, there will be no theft and no monitoring in equilibrium (since this ensures that the collective punishment is sufficient to deter theft). Otherwise, there will be positive theft and positive monitoring in equilibrium (it is this latter case that will be important for our empirical testing). Summarizing:

PROPOSITION 2: If f $\geq$ 2t; there exists a unique symmetric sub-game perfect equilibrium such that $m_i^c = a_i^c = 0$ for $i = 1,2$ (13)

If t < f < 2t, then, the unique symmetric sub-game perfect equilibrium (mc,ac) satisfies

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(*)and the social cost of water by $\frac{\partial\{2[\kappa mf(q-q^r)^2 + \psi(m)]\}}{\partial t} = \frac{t}{\kappa fm} > 0$ (**) where, $\frac{\partial \psi(m)}{\partial t} = 0$ since the monitoring effort, m and the price of water, t are both choice variables of the WA.A mere comparison between (*) and (**) is not straightforward. However, when the parameter $\kappa$ is chosen to be sufficiently small, it can be well the case that $\frac{t}{\kappa fm} > 2(t-\gamma)\frac{1}{g''(q)}$ ensuring that in the presence of theft, an equilibrium price of water lower than $\gamma$ is indeed socially beneficial.

[12] One may think of observable sunk investments (such as tools and equipments) being made by members of the cooperative, and which would commit them to a higher monitoring intensity. For instance, it is widely observed in countries like Tunisia that landlords build little houses in their farms where they can keep some farm equipments for daily use and where both landowners and agricultural laborers may spend some time.

[13] We thereby sidestep some of the issues in the literature on optimal enforcement - see Cremer (1990), Sanchez & Sobel (1993), Chander & Wilde (1998), Millock & Salanie (2005).

$$a^c = \frac{(2t-f)}{2\kappa m^c f'} \tag{14}$$

And $m^c : \frac{(2t-f)(2f-t)}{4\kappa (m^c)^2 f} = \psi'(m^c)$ (15)

**See the appendix for the proof.**

Peer monitoring not only reduces the incentives for theft (incentive effect) but may also allow each cooperative member to shift the cooperative fine on to the other (distributional effect).

### *2.3 Comparative Statics with Quadratic Monitoring Costs*

To obtain explicit solutions where possible we assume that monitoring costs take the quadratic form $\psi(m) = \frac{1}{2}bm^2$ where b > 0. We start by examining the impact of monitoring[14], the price of water and the level of punishment on the incidence of theft in equilibrium. As one might intuitively expect, theft is decreasing in monitoring and punishment levels and increasing in the price of water[15]

$$\frac{\partial a^c}{\partial m^c} = \left(\frac{2t-f}{\kappa f}\right)\left(-\frac{1}{2(m^c)^2}\right) < 0 \tag{16}$$

$$\frac{\partial a^c}{\partial f} = \frac{(2t^2 + f^2 - 6ft)}{3\kappa m^c f^2 (2f-t)} < 0 \tag{17}$$

$$\frac{\partial a^c}{\partial t} = \frac{1}{6\kappa m^c f}\frac{(7f-2t)}{(2f-t)} < 0 \tag{18}$$

Equilibrium monitoring levels are decreasing in the cost parameter b, increasing in the price of water and decreasing in the punishment rate[16] :

$$\frac{\partial m^c}{\partial b} = -\frac{m^c}{3b} < 0 \tag{19}$$

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[14] The monitoring effort is chosen in the first stage of the game, and is therefore a parameter in the second stage when the farmer chooses the amount of water to use and the amount to report.

[15] Equations (17) and (18) are indeed coming from equation (14) and from the quadratic form of the monitoring cost $\psi(m) = \frac{1}{2}bm^2$ Replacing the general monitoring cost function by its quadratic form into Equation (15) yields an explicit expression of the equilibrium monitoring effort $m^c = \left(\frac{(2t-f)(2f-t)}{4\kappa bf}\right)^{\frac{1}{3}}$.This allows us to derive the comparative static results $\frac{\partial a^c}{\partial f}$ and $\frac{\partial a^c}{\partial t}$

[16] Equations (20) and (21) are derived from equation (15) when the general monitoring cost function is replaced by its quadratic form $\psi(m) = \frac{1}{2}bm^2$. This yields the explicit expression of the equilibrium monitoring effort given in footnote 15.

$$\frac{\partial m^c}{\partial t} = \frac{1}{12b}\frac{(5f-4t)}{\kappa(m^c)^2 f^2} < 0 \qquad (20)$$

$$\frac{\partial m^c}{\partial f} = \frac{(t^2 - f^2)}{6\kappa b(m^c)^2 f^2} < 0 \qquad (21)$$

It is interesting to explore whether the equilibrium monitoring effort is efficient. For this purpose, we consider the second-best problem faced by the WA as a social planner who can control monitoring decisions of farmers but not their water use choices, nor their reports once monitoring decisions have been made. Moreover, assume that the WA cannot affect the incentives of theft for given monitoring efforts. In particular, the WA cannot ensure that farmers do not steal. The WA picks a monitoring effort, m* that maximizes the following social welfare function[17]

$W_e^c(m) = 2[g(q^c) - (c+\gamma)q^c - fa^c(m) - \psi(m)]$,

Where $a^c(m) = \frac{2t-f}{2\kappa mf}.a^c(m)$ is the amount of water stolen by a peer farmer in the symmetric equilibrium when cooperative members non-cooperatively choose how much water to use and to steal, taking for a given the level of monitoring applied by the social planner. The second-best efficient monitoring level which equates the marginal reduction of the total cooperative fine to the marginal cost of monitoring satisfies

$$\frac{(2t-f)}{2\kappa m^* f} = \psi'(m^*) \qquad (22)$$

We show that, for the case of quadratic monitoring costs, the equilibrium monitoring effort is lower than the (second-best) efficient level for reducing theft,

i.e., $m^c < m^*$ where $m^* = \left(\frac{2t-f}{2\kappa b}\right)^{\frac{1}{3}}$ and $m^c = \left(\frac{(2t-f)(2f-t)}{4\kappa bf}\right)^{\frac{1}{3}}$.

This is because, in addition to reducing the incidence of theft, monitoring increases the risk that the party doing the monitoring will have to bear the whole punishment[18], and this second effect (which is purely distributional) acts as a disincentive to undertaking the efficient level of monitoring.

### *2.4 Endogenous Punishment*

Here we extend the model to the punishment rate f to be chosen collectively by cooperative members at an initial contracting stage, subject to a cost of inflicting punishment $\varphi$(f) which is increasing and sufficiently convex to ensure an interior solution. This cost may be pecuniary or may correspond to costs in the deterioration of social relations that occur when punishment is inflicted on members of a close-knit society. Members choose the punishment

[17] The farmer's optimal water use is independent of the type of water institution, centralized management or cooperatives, i.e., $q^{cs} = q^c = q$ given by (1). This is the case (and cannot be stated as a general conclusion) because the price of water, t which affects the level of water chosen by a farmer is set by the WA in both institutions.

[18] The explanation relates to the fact that the probability of catching a cheating member increases in her monitoring by others and in her own level of theft. When a farmer monitors her peer intensively she may reduce significantly her incentives for theft, reducing thereby the likelihood of detecting her stealing, and increasing the expected fine faced by the farmer as a result of her own equilibrium level of theft. This is like a "reverse business stealing" externality that lowers the farmer's monitoring below the efficient level.

level $f^c$ that maximizes an objective function defined as the sum of cooperative members' surpluses: $2\left[g(q^c)-cq^c-tq^{rc}-fa^c-\frac{1}{2}b(m^c)^2\right]-\varphi(f)$ plus the surplus of the WA, which is equal to its revenue from water proceeds, 2tqrc, from which is deducted the cost of supplying water to the cooperative area, $2\gamma$ qc.

$$\underset{\max\in(t,2t}{\overset{c}{W}}(f)=2\left[g(q^c)-(c+\gamma)q^c-fa^c-\frac{1}{2}b(m^c)^2\right]-\varphi(f) \tag{23}$$

This has a first-order condition[19]:

$$f^c:\frac{1}{3\kappa f^2m^c(2f-t)}6(f^c)^3+t^3-4f^2t=\varphi'(f) \tag{24}$$

which is also sufficient to identify a global maximum[20] .

From this we can show that the punishment level is increasing in monitoring costs. Totally differentiating the first-order condition with respect to f and b and rearranging yields:

$$\frac{\partial f^c}{\partial b}=-\frac{1}{\left(\frac{\partial^2W^c(f)}{\partial f^2}\right)}\frac{\left[6(f^c)^3+t^3-4(f^c)^2t\right]}{2\kappa(f^c)^2(2f^c-t)}\left(-\frac{1}{(m^c)^2}\frac{\partial m^c}{\partial b}\right)>0 \tag{25}$$

The above expression is positive because $\frac{\partial m^c}{\partial b}$<0 and $\left(\frac{\partial^2W^c(f)}{\partial f^2}\right)$<0. This result shows that the two instruments, monitoring and punishment, are substitutes. An increase in the cost of one implies an increase in the equilibrium amount of the other.

### *2.5 Cooperative Size*

The analysis thus far has remained restricted to the two-farmer cooperative. In practice, however, most cooperatives for which water irrigation is based on aquifers involve up to as many as 40 farmers, and most involve more than 100 farmers when irrigation is based on surface methods. Unfortunately it is difficult to find analytical solutions for optimal cooperative size[21], but in a companion paper we report simulations[22] that suggest (though they do not prove) two relationships that we examine further in our empirical section below.

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19 Differentiating the cooperative welfare function with respect to f yields $\frac{dW^c}{df}=2\{[g'(q^c)-(c+\gamma)]\frac{\partial q^c}{\partial f}-a^c-f\frac{\partial a^c}{\partial f}-2\frac{1}{2}bm^c\frac{\partial m^c}{\partial f}-\varphi(f)=0$

Taking into account that qc does not depend on f (i.e. $\frac{\partial q^c}{\partial f}$ =0) and by replacing ac, $\frac{\partial q^c}{\partial f}$ and $\frac{\partial m^c}{\partial f}$ by their expressions given respectively by equations (14), (17) and (21) derived in the comparative statics section, we obtain the first-order condition represented by equation (24) in the text.

20 This follows from the assumption that the cost of inflicting punishment, $\varphi$ (f) is sufficiently convex, which ensures the concavity of the objective function $W^c$ (f), i.e., the second derivative of $W^c$ with respect to the punishment rate is negative,

$$\frac{d^2W^c(f)}{df^2}=\frac{1}{9\kappa 2bm^3f^3(2f-t)}\{6\kappa bmf^2(9f-4t)-(6f^3+t^3-4f^2t)(4f-t)(t^2-f^2)\}-\varphi''(f)<0$$

21 See the Appendix (C. Cooperative size) for details.

22 Full details of simulation results are in our companion paper (Mattoussi & Seabright 2007).

First, the incidence of theft appears to increase in cooperative size (it is hard to show this analytically because while cooperative size apparently increases the incentives of members to free-ride on monitoring as well as to steal from each other, it also increases the maximum punishment that would be incurred by a member who is the only one to be caught, which acts as an incentive in the opposite direction). Secondly, the optimal size of a cooperative appears to be a (weakly) decreasing function of monitoring costs.

### *2.6 Water-Saving Technology and the Incidence of Theft*

It seems plausible that farmers' incentives to steal water may be influenced by the water-intensity of the technology they use, with water-saving technologies reducing the incidence of theft. However, this conclusion is less straightforward than it seems. Equation 14 indicates that theft is not influenced by the productivity of water but only by such variables as price, punishment levels and monitoring costs. Water use is definitely affected by productivity, but theft is the difference between actual water use and reported water use.

Mattoussi (2007) develops a model in which water theft and technology adoption interact in two ways[23]. First, the adoption of water-saving technology directly affects theft by increasing the ease of detection (the settings of a drip irrigation mechanism reveal more easily[24] the amount of water being used). Secondly, the amount of expected theft reduces the willingness of farmers to pay the fixed cost associated with technology adoption, since farmers will not pay to economize on the use of a resource they intend to use without paying for. Therefore technology adoption is expected to be more likely, not only when the price of water is high in the relevant range of low to medium prices (since that increases the incentives of farmers to economize on the resource they intend to pay for) but also when punishment rates are high and when monitoring costs are low, since they reduce the amount of expected theft in equilibrium. Since these variables do not explain all the variation in expected theft, we should therefore also expect that the equilibrium level of theft itself reduces the incentive for technology adoption. We test these predictions below.

### *2.7 Summary of Empirical Hypotheses*

The predictions of the models set out above are as follows:

- Theft increases in the price of water.
- Theft decreases in punishment levels.
- Theft increases in monitoring costs.
- The optimal punishment increases in monitoring costs.

The predictions of the simulations in Mattoussi & Seabright (2007) are as follows:

- Theft increases in the size of the cooperative.
- The optimal cooperative size decreases in monitoring costs.

The predictions of the technology adoption model in Mattoussi (2007) are as follows:

- Adoption of water-saving technologies increases in the level of punishment.

[23] The model does not involve a cooperative setting, just a farmer facing monitoring from the WA. However, there is no reason to think the results would be qualitatively different in a cooperative setting, though the generalization is not straightforward because of the endogeneity of monitoring levels.

[24] Indeed, drippers with controllable low rates (e.g., liters or m3per hour) can be easily installed to effectively accommodate the optimal needs of any crop (e.g., choosing the optimal distance between dripper and plant). Thus, for example placing the drippers quite far from the lines of plants or the observation of white areas around plants (because of the high degree of salinity) means that carelessness is involved. Moreover, because of their repeated relationship with farmers, and their know-how in the agricultural sector (as a result of their long experience), government agencies (and even skilled farmers) can determine the approximated water being used by casual observation.

- Adoption of water-saving technologies decreases in monitoring costs.
- Adoption of water-saving technologies increases in the price of water in a relevant range of low to medium water prices.
- Adoption of water-saving technologies decreases in the equilibrium incidence of theft.

## 3. Testing the Model: Data

### *3.1 Data Sources*

This section tests our predictions using survey data from 2001-03 for 49 irrigation cooperatives, the so-called Collective Interest Groups CIG in five governorates in the north of Tunisia. The key question for investigation is what determines the rate of theft of water, a highly scarce resource in this region. Among the difficulties in testing such predictions are that some of the likely determinants of theft (such as monitoring levels) are not observable, at least by the econometrician, while others (such as cooperative size and the levels of fines) are very likely to be endogenous. There is also the difficulty that theft, as such, is not observable. What we do observe is the difference between total water used by each cooperative and the aggregate amounts reported by the water meters of the members. It is possible that some of this difference may be due to technical problems such as leakage from pipes. However, as we shall see below, it is extremely unlikely that such technical explanations can account for all or even most of the discrepancy, simply because our results show that the discrepancy is related to economic rather than purely physical variables. People respond to prices, whereas pipes do not, so we interpret the result that prices influence the difference between water used and water reported as a sign that the difference is substantially due to theft. The conclusion is reinforced by our results for other economic determinants of theft.

The survey was carried out by one of us (Mattoussi) in five governorates of a northern region of Tunisia, a country which faces severe and growing problems of water scarcity. Government policies for the last three decades have promoted irrigated cropping patterns at the expense of dry-land farming, and low prices for water have led to cropping patterns based on water-intensive crops. Indeed, despite the country's comparative disadvantage in water-intensive crops, the main exported farm goods are dates, whose water consumption averages 15.000 m3 per hectare, and citrus fruits which consume on average 10.000 m3 per hectare (note that a crop is considered water-intensive when it consumes more than 6.000 m3 per hectare). In this agro-climatic zone, wheat, olives and gardening products are the main crops in the winter season, where wheat is by far the most important in terms of cultivated area (76.7%). Tomatoes, water melon, potatoes, grapes, apples and pears are the main crops in the summer season. The region receives moderate and erratic rainfall averaging 570 mm per year, mainly concentrated during the winter season from December to February. Farmers therefore rely heavily on water sources controlled by water agencies for the remainder of the year. The region is mostly flat, with hills in only 30% of its total area. The governorates under study vary considerably with respect to geographical and socioeconomic characteristics (see Mattoussi, 2006 for further details).

A centralized mode of regulation dominated water management in the country until 1987 except in the south, where in the region of "Djerid", a system of participatory management has been in place since the XIII century. Under the latter system, the distribution of water in the oases was held by a "syndic" chosen by the beneficiaries, assisted by the "Kbar" (community elders). Under the centralized scheme, the management responsibilities of government agencies include providing public areas with water, dealing with the operation and maintenance of irrigation systems, replacing equipment, monitoring farmers to reduce the occurrence of theft when the irrigated area is equipped with water measuring devices, collecting water proceeds, and so on. However, since 1987, participatory management was implemented through so-called Collective Interest Groups (CIGs). CIGs have become a central component of governmental reforms in the water sector. The participatory approach speeds up the transfer of water management from the administration to beneficiaries (in the period between 1987 and 2003, the number of CIGs increased from 100 to over 1000). The simplest water distribution plan is that related to rural drinking water, then come small and medium scale irrigation networks whose areas vary between 20 ha and 700 ha. CIGs for irrigation cover 56% of irrigated areas equipped by public investment, with a total surface area of 121.000 hectares. CIGs began by assuming energy costs first, extending afterwards to salaries of pump attendants, thus relieving the state of all energy and personal costs, The central WA sets water tariffs . The Agricultural Regional Development Commissions (ARDC) — the regional authorities in charge of running the public irrigated areas on behalf of the central WA — still support simple CIGs for major maintenance works and replacement of equipment.

Most governorates of the survey have experienced participatory management since 1989 with the exception of Zaghouan for which such management was introduced in 1960 through the project of "Jenan Zaghouan". In 2003 the region contained more than 482 CIGs of which 182 were for irrigation (among these, 95 CIGs are equipped with individual water meters); the latter manage 58.8% of publicly irrigated areas.

Our target population is CIGs equipped with individual water meters, which totaled 95 in the region where the survey was carried out. Only 49 of the 95 CIGs had available data of the kind needed for our study (for instance, data on cooperative accounts, including information on the total amount of water delivered to the cooperative, the total reported usage indicated by the members' water meters, cropping patterns and so on). We are not aware of any biases that may be reflected in our results by this partial availability of data, but evidently the possibility of selection bias cannot be ruled out.

Our data consists of information about the number of cooperative members, the price of water charged to farmers, in addition to the socioeconomic characteristics of cooperatives managers (members who are in charge of running cooperatives), such as their level of education and their age. We also have information about geographical characteristics, such as the hilly parts of a cooperative's land in percentage and the sources of water supply available to farmers, including those not controlled by government agencies. In addition there is data concerning the cooperatives' cultivation processes, namely cropping patterns and the diffusion of drip and sprinkler irrigation systems.

The dataset is of an unbalanced panel type, for three years (from 2001 to 2003) for 39 cooperatives, and for two years (from 2002 to 2003) for the remaining 10. Almost all data was jointly provided by the ARDC of the five governorates, by the technical directors of cooperatives who are in charge of the cooperatives' accounting operations, by the pumping attendants when supply sources are boreholes and by the central WA when some data is not available for some cooperatives. Only a little data was exclusively collected from cooperatives managers. We also obtained information from the cooperatives' managing authorities about the types of natural catastrophes that had stricken cooperatives — about whether or not they had caused damage — and we also cross-checked our estimates of losses in cooperatives' production with the Cells of Agricultural Development (CAD) for the five governorates. We also asked about the prices of farm goods produced by the region in previous and current season.

Before proceeding with the econometric analysis it is important to clarify the way in which we propose to measure the monitoring costs faced by the cooperative.

### 3.2 Proxy Measure of Peer Monitoring Costs

Given that monitoring levels are not directly observable, we needed to find suitable proxy measure. The one we have chosen is distance.

- DISTANCE: is the length (measured in kilometers) of the portion of the main road (linking the cooperative area to the agglomeration) which separates the entrances of the cooperative area and the agglomeration (these entrances are officially determined by municipalities where the agglomeration and the cooperative area are located).

This is likely to increase monitoring costs because it reduces the ability of cooperative members to observe the behavior of other members as a byproduct of their own day-to-day activities.

It is important to note that monitoring costs cannot by themselves be used as excluded instruments for the endogenous variables, since the theory predicts that monitoring costs will determine both the choice of institutions (such as the cooperative size and punishment rate), and also the level of theft conditional on that institutional choice. However, we can nevertheless investigate whether monitoring costs also directly influence the choice of institutional characteristics; we do this in Section 4 below.

Table 1 presents the descriptive statistics of our empirical variables.

The variables we will use in the subsequent empirical analysis[25] are defined as follows:

- WATER THEFT: is the differential between the total amount of water delivered to the cooperative area and that indicated by cooperative members' water meters, expressed as a percentage of the total amount delivered to the cooperative.
- SIZE: is the number of active farmers who grow crops on land irrigated by the cooperative.
- PUNISHMENT RATE: is the number of days for which farmers are denied access to irrigation, expressed per 10.000 m3 of divergence between the total amount of water used by the cooperative as a whole and the total amount of water indicated by the cooperative members' water meters. This divergence in quantities represents the total liability which will be shared between cooperative members who are caught stealing.
- DRIP: is the percentage of the land irrigated by the cooperative equipped with drip irrigation systems.
- WATER SOURCE: scores (+4) when the source is a dam with a storage capacity of between 400 and 700 millions of $m^3$ of water (qualified as a big dam). It scores (+3) when the source is a dam with a storage capacity between 50 and 400 millions of $m^3$ of water (qualified as a medium dam). It scores (+2) when the source is a dam with a storage capacity between 10 and 50 millions $m^3$ of water (qualified as a small dam). It scores (+1) when the source is a dam with a storage capacity between one and 10 millions of $m^3$ of water (qualified as a very small dam) or when it is a hilly lake. It scores (0) when the source is a borehole.
- ALTERNATIVE SOURCE: is the percentage of active farmers who have alternative sources of water supply which are not controlled by the ARDC, such as lakes or rivers.
- REVENUE SHOCK: this is an index, drawn up in discussion with the representatives of each cooperative, capturing whether the cooperative had experienced a good or bad previous year relative to what is perceived as normal. It scores (-2) when more than 50% of the cooperative area was ravaged in previous seasons by some natural catastrophes as floods, scorching heat and crops diseases, and in addition to a decrease in the prices of the main farm goods produced by the cooperative. It scores (-1) if up to 50% of the

[25] Except the proxy for monitoring costs which has already been defined above.

cooperative area was ravaged by some natural catastrophes as floods, scorching heat and crop disease, and there was no major change in the prices of the main farm goods produced by the cooperative. It scores (0) if farmers had enjoyed favorable environmental conditions and there was no rise in the prices of the main farm goods produced by the cooperative. It scores (+1) if farmers had enjoyed favorable environmental conditions but there was a small rise in the prices of the main farm goods produced by the cooperative. It scores (+2) if farmers had enjoyed favorable environmental conditions and there was a significant rise in the prices of the main farm goods produced by the cooperative.

- PREVIOUS SPRINKLER: is the percentage of the land irrigated by the cooperative which was equipped with sprinkler systems in the previous year.
- ADVERSE CLIMATE: scores (+2) when the cooperative faces both peak heat higher than 40 degree Celsius in the shade during the three months of July, August and September, and lower than average annual precipitation (lower than 500 mm). It scores (+1) when it faces either peak heat higher than 40 degree Celsius in the shade during the three months of July, August and September, or lower than average annual precipitation (lower than 500 mm) and scores (0) otherwise.
- RAINFALL: this is a somewhat crude measure of the variation in the annual precipitation of the region where the cooperative area is located. It scores (+2) when it faces high annual precipitation (higher than 600 mm). It scores (+1) when it faces normal annual precipitation (between 600 mm and 200 mm); and scores (0) when it faces lower than normal annual precipitation (lower than 200 mm).
- RED SOILS: is the percentage of the cooperative area where soil is red.
- EDUCATION: is the average number of years of schooling of the farmers who are in charge of running the cooperative.
- AGE: is the average age of farmers who are in charge of running the cooperative.
- DISTANCE TO LARGE CITY: is the distance between the cooperative area and the nearest large city where there are public infrastructures such as schools (primary and secondary), public hospitals, water systems, bridges, roads and other public buildings.
- EQUIPPED SURFACE: is the total area of the cooperative. This area is equipped with the irrigation network, e.g., primary and secondary water tubes, measuring devices and so on.
- ALTERNATIVE REVENUE: it scores (+1) when more than 10% of cooperative members have income from off-farm sources, and scores (0) otherwise.
- PRICE: is the price of one unit of water charged by the WA.
- HILLY AREA: is the percentage of the cooperative area which is hilly.
- DENSITY: is the number of individuals living in the agglomeration (village or little town) where the cooperative is located divided by the surface of the agglomeration.

## 4. Testing the Model: Results

### *4.1 Estimation of the Determinants of Water Theft*

We report here the determinants of theft — in particular, the predictions that theft is increasing in the price of water, decreasing in the punishment rate, and increasing in the size of the cooperative and the level of monitoring costs. We also investigate how theft is affected by the use of water-saving technologies. We regress water theft on the following independent variables:

- PRICE

Institutional variables:

- SIZE

- PUNISHMENT RATE

A variable controlling for the productivity of water:

- DRIP.

A proxy measure of monitoring costs:

- DISTANCE.

Control variables:

- REVENUE SHOCK: This index captures the broad characteristics of a shared revenue shock and can thereby be considered as a proxy measure of cooperative members' liquidity constraints. As will be seen below, this variable is associated with water theft in an entirely intuitive direction.
- EQUIPPED SURFACE
- AGE

Table 2 illustrates an Ordinary Least Squares (OLS) estimation of the determinants of water theft. The first equation (which is an OLS regression with clustering on cooperatives) shows that theft increases in the price of water, in the size of the cooperative and in the distance of the cooperative from the village (a positive proxy for monitoring costs). It is decreasing in the punishment rate. These four effects are all those predicted by the theory, and all are significant at 1% except the price effect which is significant at 5%. The second equation shows that the qualitative findings prove reasonably robust to the inclusion of cooperative fixed effects, although this is a very demanding test since there are only three years of data and not for all cooperatives. Under fixed effects the standard errors increase, reducing the price effect to insignificance (though without very much modifying the coefficient). Overall, though, the results clearly support the predictions of the theory.

The remaining coefficients show various controls for which theory provides no unambiguous predictions. The presence of drip irrigation (which increases the productivity of water) lowers theft. The age of the cooperative president has a positive effect on theft but this is reversed under fixed effects. The presence of a positive revenue shock lowers theft (though not in the fixed effects specification), as does the size of the equipped surface.

We now turn to concerns about the possible endogeneity of some of the right-hand-side variables (using the IV regression with clustering on cooperatives). The most likely variable to suffer from this problem is PUNISHMENT RATE; higher rates of theft might lead to increased punishment rates, for instance. This would bias downward the absolute value of the OLS parameter estimate, since the causal association of high punishment rates with low rates of theft would be offset by a reverse-causal association of high punishment rates with high rates of theft. Similar considerations might apply to Log(SIZE); high rates of theft could lead to smaller-sized cooperatives, especially if members realize that a large organization is prone to free-riding and are more likely to form break-away organizations. A variable that may be endogenous for different reasons is DRIP; members who expect to steal their water will have weaker incentives to adopt water-saving technologies. This would bias upward the absolute value of the OLS parameter estimate, since a causal association of high adoption of drip technology with low rates of theft would be reinforced by a reverse-causal association of high rates of theft with low rates of adoption of the technology.

To explore these possibilities our instrumenting strategy is as follows. Beginning with PUNISHMENT RATE, we use the idea that personal characteristics of the cooperative society managers may more likely lead them to inflict harsher punishments, and supplement these with geographical characteristics of the localities that may make harsher punishments more or less costly to inflict. Our relevant personal characteristics are captured by the variable EDUCATION. Our use of this variable is inspired by earlier evidence collected by one of us that education plays an important role in helping individuals to understand the importance of incentives and devising institutional responses to incentive problems. Seabright (1997) reports evidence from milk producers' cooperative societies in South India that more educated managers are more likely to use incentive-based methods to deter cheating by society members. For the geographical characteristics we use DENSITY; the idea is that higher population density may increase the costs in social discord of inflicting punishments, both because people depend more intensely on the land and because the punishers and the punished have to live more closely together. It is possible, however, that DENSITY also proxies for ease of monitoring and may therefore affect theft directly and not just via PUNISHMENT RATE. We test for this below and find the exclusion restriction justified. Finally, we use WATER SOURCE as an instrument since it seems likely that larger sources of water make it easier to exclude individuals who steal, since more third parties are likely to be affected and therefore the is more pressure to sanction those who steal water. As an instrument for Log(SIZE) we use an additional geographical variable which is HILLY AREA; in areas that are hilly the size of the cooperative is more likely to be limited by topographical constraints.

Finally, as instruments for DRIP we use one geographical and two climatic variables that influence the productivity of the technology and two variables that capture the ability of farmers to afford the necessary investment. RED SOILS are those with lower water retention on which drip technology therefore saves more water. RAINFALL and ADVERSE CLIMATE capture respectively the relative abundance and scarcity of water to the cooperative. ALTERNATIVE REVENUE captures the greater economic ability of the farmers concerned to afford the investments in the drip technology, while PREVIOUS SPRINKLER captures the awareness of farmers of the benefits of water-saving technologies.

A word of caution is in order. Although we find the exclusion restrictions plausible we cannot rule out *a priori* that the proposed instruments do in fact affect theft directly, so we pay particular attention to the statistical tests of over-identifying restrictions that we report on all the instrumental variables specifications below.

Table 3 shows the results of these instrumental variables estimations. We instrument first for PUNISHMENT RATE, then for PUNISHMENT RATE and DRIP, and finally for both of these variables as well as for Log(SIZE). In the final equation we replace EDUCATION (which may not be quite appropriate as an instrument for Log(SIZE) since larger cooperatives are more likely to have educated individuals to call upon) by the distance of the cooperative from the nearest large city which is a more clearly exogenous variable, and which is a significant predictor of education as we show in Table 4 below.

These results provide a striking confirmation of our hypotheses about the determinants of theft, even when we control for the endogeneity of institutional rules and technology adoption. All the variables that were significant in our OLS specification remain significant in the 2SLS specification at 5% at least and in most cases at 1%. They also show that our concerns about endogeneity are justified, though more for some variables than for others. The coefficient on PUNISHMENT RATE more than doubles in absolute magnitude compared to the OLS specification, suggesting that there is indeed a reverse causality effect of theft that tends to increase punishment rates. The Durbin-Wu-Hausman tests reject exogeneity of PUNISHMENT RATE at less than 5% significance. The coefficient on DRIP falls in absolute magnitude by around a quarter, confirming our conjecture that the OLS estimate is biased away from zero. A Durbin-Wu-Hausman test on this variable alone (not reported) rejects exogeneity, at around 10% significance. The coefficient on SIZE, however, does not change in a consistent way — the effect of instrumenting relative to OLS depends on the specification in question, and the coefficient does not change very much. Indeed a Durbin-

Wu-Hausman test on this variable alone (not reported) fails to reject exogeneity at anything close to conventional significance levels, although the joint test of the exogeneity of all three variables is clearly rejected. It is also worth noting that the coefficient on PRICE increases when we instrument for the other variables, suggesting that the impact of PRICE on theft is even stronger before institutional responses act in mitigation.

The rest of the variables have the expected signs and are significant at a 5% or better level of confidence. The coefficient on DISTANCE is positive, because it reduces the expected level of monitoring, increasing thereby the scope for theft. The coefficient on REVENUE SHOCK is negative as expected. We are not sure how to interpret the positive coefficient on AGE (as we show below, AGE is significantly associated with higher punishment rates, which themselves reduce theft). It may indicate that the older the farmers who are in charge of running the cooperative are (cooperative managers or leaders[26] ), the less inclined they are personally to monitor the other cooperative members (preferring to rely instead on more stringent punishment) to reduce their incentives of theft. This is in line with the findings of Niels Hermes, et al. (2000) who report evidence (from participants in 102 lending groups in Eritrea) that peer monitoring by group leaders helps to reduce moral hazard behavior of group members[27] and increase the repayment performance of groups. Similarly it is not clear how to interpret the negative coefficient on EQUIPPED SURFACE. The equipped surface of the cooperative may well be associated with the wealth of the region where the cooperative is located, which tends to be positively associated with the productivity of investment by the WA in the region concerned. If so, it may be negatively associated with liquidity constraints, and thereby be associated with lower incentives of theft.

Finally, the instruments comfortably pass the Hansen test of over-identifying restrictions. Interestingly, our exploration of EDUCATION as an instrument has an important and intuitive interpretation, the importance of which goes far beyond this particular context (and is supported by the work reported in Seabright, 1997 to which we referred above). Education has a powerful effect on the choice of institutions, in a direction that tends to reduce theft, but has no direct effect on theft apart from this. Education appears to have little direct effect on honesty but a substantial effect on the ability of people to design incentives that make honesty a better policy.

### *4.2 Institutional Characteristics*

In this section we report more detailed econometric evidence about how people involved in the cooperative determine the institutional characteristics, notably the punishment rate and the cooperative size. We also consider the determinants of the adoption of water-saving technologies.

#### *4.2.1 Endogenous punishment*

Here we report the results of our estimates of the determinants of the PUNISHMENT RATE. The independent variables we use are the three discussed above, plus two controls:

Personal characteristics

- EDUCATION.

Physical characteristics affecting the ease of inflicting punishment:

- DENSITY.

[26] The age of the cooperative manager might well be interpreted as a positive proxy for the costs of monitoring performed by this leader.

[27] The moral hazard behavior of borrowers is divided into *ex ante* moral hazard issues, such as shirking in the productive efforts (Varian, 1990) and poor project selection (stiglitz, 1990); and *ex post* "strategic default" (Armendariz De Aghion, 1999), where borrowers choose not to repay the loan even if they are able to do so.

- WATER SOURCE.

Control Variables:

- DISTANCE.
- AGE.

Table 4 reports two specifications, both using OLS with clustering on cooperatives. In the first (equation 4.1), we use just the first three variables. In the second (equation 4.2), we add controls for DISTANCE and AGE. The purpose of controlling for DISTANCE is twofold. First, it is to see whether monitoring costs are directly influencing the choice of punishment; the answer is that they are not. Secondly, it is to see whether its inclusion changes the coefficient on DENSITY, which might indicate that the latter is in fact proxying for monitoring costs and may therefore have a direct impact on theft. In fact DISTANCE is insignificant in the second equation and its inclusion leaves the coefficient on DENSITY unchanged; this increases our confidence in its validity as an instrument in the theft equations reported above, as well as in the conclusion that monitoring costs do not directly affect the choice of punishment rate. The latter is responding instead to factors that affect the cost of inflicting punishment, as well as to the ability of cooperative managers to understand the significance of incentives in the effective running of the organization.

AGE is indeed significant when included, but it does not affect the values of the other coefficients in any important way. One plausible interpretation for its positive coefficient is that older individuals are likely to be more experienced in the use of incentives.

We also undertake a two-stage least squares estimation with clustering on cooperatives, instrumenting EDUCATION[28] with DISTANCE TO LARGE CITY[29], but this does not change the coefficient[30] significantly and the Durbin-Wu-Hausman test comfortably accepts the hypothesis of exogeneity, so we do not report it here.

#### *4.2.2 Cooperative size*

We report here the results for the determinants of Log(SIZE). Once again we use an approach based on both personal characteristics and geographical characteristics. We use the same variables as for PUNISHMENT RATE, plus two additional geographical variables that are likely to be particularly relevant to the determination of cooperative size. The first is ALTERNATIVE SOURCE, which measures the proportion of farmers who have access to water sources that are not controlled by the WA (this is likely to reduce cooperative size for any given population since it decreases the incentive for farmers to join the cooperative). The second is HILLY AREA which is likely to have a negative effect on cooperative size by reducing the populated area in a given community. We expect WATER SOURCE to have a positive coefficient since larger sources make it easier to support more cooperative members.

As with PUNISHMENT RATE we shall also try to see whether DISTANCE is a significant regressor. Unlike in the case of PUNISHMENT RATE there are some reasons to fear that EDUCATION may be endogenous, since it is likely that larger cooperatives will have more educated members to call upon in the management of the cooperative. This would tend to

[28] Cooperative managers are chosen or elected by the other cooperative members, so their level of education is very likely to be endogenous.

[29] This is a plausible positive proxy for education infrastructure or/and for proximity to schools.

[30] The positive coefficient on EDUCATION (as reported in Table 4) is unlikely to be due to the fact that more educated individuals are richer and can afford to pay higher fines, since the punishment is measured in terms of the length of time for which water is cut off from a cheating member — a measure whose cost is increasing in the amount of land cultivated by the farmer concerned.

bias downward the OLS parameter estimate (since a negative causal link would be offset by a positive reverse-causal link). We therefore try to endogenize EDUCATION using DISTANCE TO LARGE CITY as an instrument.

This leaves us with the following variables in the main equation:

- EDUCATION
- WATER SOURCE
- ALTERNATIVE SOURCE DENSITY
- HILLY AREA DISTANCE

Table 5 shows our results.

The findings are consistent with those for PUNISHMENT RATE. EDUCATION has an important influence on cooperative size and in the expected direction — which is that more educated members choose smaller cooperatives. This finding is strengthened when we instrument for EDUCATION, since there is an effect of reverse causality making larger cooperatives contain more educated members. Instrumenting increases the absolute magnitude of the coefficient on EDUCATION by around three-quarters, a difference that is significant at under 5%.

Once again DISTANCE is insignificant and makes no difference to the coefficients on the other explanatory variables, including DENSITY. This implies that cooperative size is not influenced directly by monitoring costs, but rather by the various geographical constraints that directly influence the costs and benefits of size, with more educated managers of the society appreciating the benefits of smaller size in terms of theft reduction. The insignificance of DISTANCE and its lack of correlation with DENSITY also strengthen our confidence in the exclusion restrictions in the theft equations in Table 3.

#### *4.2.3 Adoption of drip-irrigation technology*

We report here the results for the estimation of DRIP (we are estimating the equation on cooperative-level data; we do not have data on the adoption decisions of individual members). Our model predicts that adoption of water-saving technologies will be increasing in the price of water and the level of punishment, and decreasing in the equilibrium incidence of theft and in monitoring costs. In testing these predictions, we shall want to control for factors that affect the productivity of the technology (which may vary from one place to another according to agro-climatic conditions and cropping patterns) and for factors that affect the ability of farmers to afford the capital investments involved (access to capital may be positively correlated with adoption incentives). We also control for the degree of awareness on the part of farmers of the technology benefits that have higher productivity than traditional irrigation, captured by the variable PREVIOUS SPRINKLER.

Our independent variables are therefore the following:

- PRICE.

Variables controlling for the productivity of the technology:

- RED SOILS RAINFALL
- ADVERSE CLIMATE

A variable capturing farmers' wealth and liquidity constraints:

- ALTERNATIVE REVENUE.

A variable capturing previous knowledge:

- PREVIOUS SPRINKLER.

Other control:

- HILLY AREA.

In addition we test the hypothesis that expected levels of theft will influence the incentives to adopt water-saving technology (in the sense that people who expect to steal water will be less likely to invest in the technology). We do this by including the variable WATER THEFT, but since we expect this may be endogenous we instrument it using DISTANCE, which we know from Table 3 to be an important determinant of theft, and one which is not directly significant in the DRIP equation. We also tested the inclusion of PUNISHMENT RATE but since this was insignificant we do not report it here. Table 6 illustrates the results.

In equation 6.1, the coefficient on PRICE is positive[31] as expected. The coefficient on RAINFALL is negative, since the more rainfall the cooperative receives during the year, the more likely it is that cooperative members will have low water requirements for irrigation, and the less heavily they will rely on sources of water controlled by government agencies. Hence, they have lower incentives to invest in expensive water-saving technologies. Similar considerations apply to the positive coefficient[32] on ADVERSE CLIMATE. RED SOILS absorb more water and thus enhance the need for water-saving technologies. The coefficient on ALTERNATIVE REVENUE is positive, the higher the income from off-farm activities, the more likely are farmers to have the necessary funds for investing in new technologies. The positive coefficient on PREVIOUS SPRINKLER is along the expected lines. The theoretical predictions are therefore supported by the evidence except for the coefficient on PUNISHMENT RATE, for which no support is found.

In equation 6.2, the two striking findings are that predicted water theft has a negative impact on technology adoption, as expected, and that including this regressor increases the coefficient on price. This implies that the effect of price on technology adoption would be even stronger than it is if it were not for the fact that higher prices also encourage theft.

#### *4.2.4 Conclusions on institutional characteristics*

The results of these three exercises on the determinants of PUNISHMENT RATE, Log(SIZE) and DRIP can be summarized as follows:

The choice of PUNISHMENT RATE and Log(SIZE) do seem to be influenced by geographical factors which affect the costs and benefits of making these respective choices. DENSITY makes punishment more difficult and larger cooperatives easier. These choices are also clearly influenced by the education levels of the farmers who run the cooperatives. The latter appear to be aware of the importance of their choices for effective cooperative management, and more educated people make these choices in ways that tend to reduce theft. We have found, however, no direct evidence that high monitoring costs in themselves lead to theft-reducing choices of these institutional variables. This may of course be due to the fact that DISTANCE is a very imperfect proxy for monitoring costs. We have considered whether our variable DENSITY could in fact be proxying for monitoring costs, which would suggest a role for such costs in both the choices of PUNISHMENT RATE and Log(SIZE). However, the results of our regressions on the determinants of water theft show that DENSITY is insignificant in all specifications, which is inconsistent with the hypothesis that this variable is an alternative proxy for monitoring costs. We are left to conclude, then, that while monitoring costs directly affect theft, they do not directly affect institutional characteristics,

[31] This finding is in line with findings reported by Caswell and Zilberman (1985) who examined the determinant factors in the adoption of furrow, sprinkler and drip irrigation by fruits growers in the San Joaquin Valley of California. They found that an increase in water tax encouraged fruit growers to adopt modern technologies associated with water cost-saving.

[32] This positive coefficient captures a more general range of adverse climatic conditions than simple water scarcity, and which have been found by other researchers to be associated with technology adoption (see Koundouri, P. et al., 2006).

which are responsive to other factors that influence their costs and benefits as well as to the education levels of the farmers who manage the organization.

The results on the determinants of DRIP do, however, show a direct role for monitoring costs in influencing adoption decisions. When theft is expected to be high, adoption is less likely, exactly as predicted by the theory.

Nevertheless, to test the robustness of these results to alternative specifications, particularly bearing in mind the endogeneity of theft and technology adoption in each others' equations, we estimate a system of four equations using three-stage least squares regression; the results are reported in Table 7. As one can see the 3SLS results are qualitatively almost identical to the 2SLS results. This is entirely supportive of the theoretical predictions.

## 5. Conclusion

This paper investigates how cooperative members choose their institutional rules, in terms of the cooperative size and the level of punishment inflicted on cheating farmers who are caught stealing. Thereafter, we show how the institutional rules and formal incentives affect farmers' decisions in terms of technology adoption and, conditional on technology adoption, in terms of water theft. Based on survey data from irrigation cooperatives in five governorates in the north of Tunisia, the econometric evidence supports the findings of the theoretical models in that the size of the cooperatives and the levels of punishment inflicted on members caught stealing respond to the perceived costs and benefits of such choices. We also find support for the role of higher cooperative size in increasing the incentives for theft and of a higher level of punishment in reducing them. Moreover, the econometric evidence lends credence to the fact that monitoring costs and the price of water increase theft and drip-irrigation technology in turn reduces it.

Overall, these results provide strong confirmation of the ability of well designed incentives to reduce theft, as well as of the fact that institutions are not just exogenously given features of the social environment but adapt to the perceived costs and benefits of designing them in particular ways. They also show that higher monitoring costs have a positive effect on the incidence of theft, though one that various institutional innovations can counteract.

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## Table 1: Summary of Descriptive Statistics

| Variable | Unit of Measure | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| **CIG** | - | 137 | 0 | - | - | - |
| **YEAR** | Year | 137 | 2 | 0.804 | 1 | 3 |
| **WATER THEFT** | Percentage | 137 | 0.37 | 0.19 | 0 | 0.846 |
| **SIZE** | Farmer | 137 | 43.07 | 39.1 | 2 | 251 |
| **PRICE** | Tunisian dinar per $m^3$ | 137 | 0.103 | 0.027 | 0.05 | 0.14 |
| **PUNISHMENT RATE** | Days access denied per 10.000 $m^3$ of water stolen | 137 | 26.25 | 9.36 | 12 | 42 |
| **EDUCATION** | Year | 137 | 5.63 | 1.93 | 3 | 10.33 |
| **AGE** | Year | 137 | 48.38 | 6.496 | 35 | 65 |
| **REVENUE SHOCK** | Index | 137 | 0.07 | 0.86 | -2 | 1 |
| **EQUIPPED SURFACE** | Hectare | 137 | 234.2 | 172.3 | 20 | 706 |
| **ALTERNATIVE REVENUE** | Binary variable | 137 | 0.39 | 0.49 | 0 | 1 |
| **DRIP** | Percentage | 137 | 0.3 | 0.13 | 0.1 | 0.6 |
| **RAINFALL** | Index | 137 | 0.95 | 0.77 | 0 | 2 |
| **ADVERSE CLIMATE** | Index | 137 | 1.08 | 0.59 | 0 | 2 |
| **RED SOILS** | Percentage | 137 | 0.2 | 0.12 | 0 | 0.7 |
| **HILLY AREA** | Percentage | 137 | 0.06 | 0.05 | 0 | 0.18 |
| **DENSITY** | Individuals per hectare | 137 | 0.26 | 0.118 | 0.12 | 0.56 |
| **DISTANCE** | Kilometer | 137 | 1.4 | 0.81 | 0 | 3 |
| **WATER SOURCE** | Index | 137 | 1.8 | 1.36 | 0 | 4 |
| **ALTERNATIVE SOURCE** | Percentage | 137 | 0.116 | 0.19 | 0 | 1 |
| **PREVIOUS SPRINKLER** | Percentage | 137 | 0.23 | 0.06 | 0.1 | 0.36 |
| **DISTANCE TO LARGE CITY** | Kilometer | 137 | 15.43 | 5 | 7 | 25 |
| **CODE** | | 137 | 25.13 | 14.2 | 1 | 49 |
| **log(SIZE)** | | 137 | 3.43 | 0.84 | 0.7 | 5.52 |
| **log(EQUIPPED SURFACE)** | | 137 | 5.2 | 0.74 | 3 | 6.56 |

## Table 2: Determinants of Water Theft

| Independent Variable | Main OLS Specification | With Cooperative Fixed Effects |
|---|---|---|
| | 1.03 | 1.425 |
| **PRICE** | (0.452)** | (1.517) |
| | 0.124 | 0.122 |
| **Log(SIZE)** | (0.0125)*** | (0.035)*** |
| | -0.0032 | -0.0108 |
| **PUNISHMENT RATE** | (0.001)*** | (0.0058)* |
| | 0.085 | 0.028 |
| **DISTANCE** | (0.0157)*** | (0.077)*** |
| | -0.38 | -1.64 |
| **DRIP** | (0.107)*** | (0.22)*** |
| | 0.0045 | -0.028 |
| **AGE** | (0.0015)*** | (0.0077)*** |
| | -0.034 | 0.0026 |
| **REVENUE SHOCK** | (0.0012)*** | (0.0153) |
| | -0.071 | -0.0039 |
| **log(EQUIPPED SURFACE)** | (0.0175)*** | (0.466) |
| | 0.079 | 0.154 |
| **CONSTANT** | (0.09) | (2.428) |
| **$R^2$** | 0.74 | 0.0006[1] |

Note: Robust standard errors (for the OLS specification) and standard errors (for the fixed effects specification) are in parentheses; *, **, and *** indicate that the estimated coefficients are significant at 10%, 5%, and 1% level.

1: R2 between is reported for the fixed effects specification.

## Table 3: Determinants of WATER THEFT

| | Eq.3.1[a] | Eq.3.2[b] | Eq.3.3[c] | Eq.3.4[d] |
|---|---|---|---|---|
| **Variable Instrumented:** | PR | + DRIP | + Log(SIZE) | as 3.3 |
| | **Independent Variable:** | | | |
| | 1.53 | 1.30 | 1.31 | 0.98 |
| **PRICE** | (0.51)*** | (0.48)*** | (0.55)*** | (0.562)*** |
| | 0.11 | 0.11 | 0.10 | 0.134 |
| **Log(SIZE)** | (0.02)*** | (0.02)*** | (0.030)*** | (0.024)*** |
| | -0.0076 | -0.0079 | -0.0079 | -0.006 |
| **PUNISHMENT RATE (PR)** | (0.002)*** | (0.002)*** | (0.003)*** | (0.003)** |
| | 0:081 | 0:079 | 0:079 | 0:077 |
| **DISTANCE** | (0:019) | (0:019) | (0:019) | (0:017) |
| | -0.40 | -0.31 | -0.32 | -0.28 |
| **DRIP** | (0.11)*** | (0.11)** | (0.11)*** | (0.10)*** |
| | 0.007 | 0.007 | 0.007 | 0.005 |
| **AGE** | (0.002) | (0.002) | (0.002) | (0.002) |
| | -0.030 | -0.028 | -0.029 | -0.027 |
| **REVENUE SHOCK** | (0.012)** | (0.012)** | (0.011)** | (0.011)** |
| | -0.087 | -0.084 | -0.084 | -0.084 |
| **log(EQUIPPED SURFACE)** | (0.023)*** | (0.022)*** | (0.022)*** | (0.020)*** |
| | 0.20 | 0.18 | 0.18 | 0.120 |
| **CONSTANT** | (0.12)* | (0.11)* | (0.12)* | (0.11) |
| | 1.31 | 4.10 | 4.49 | 8.52 |
| **Hansen J-stat (% sig.)** | (0.52) | (0.66) | (0.61) | (0.29) |
| **Durbin-Wu-Hausman** | 5.04 | 8.53 | 8.69 | 7.81 |
| **Test (% sig.)** | (0.025) | (0.014) | (0.033) | (0.050) |

Note: Robust standard errors are in parentheses; *, **, and *** indicate that the estimated coefficients are significant at 10%, 5%, and 1% level.
The excluded instruments are education, density, water source.
The excluded instruments are as in 3.1 plus red soils, rainfall, adverse climate, previous sprinkler, alternative revenue
The excluded instruments are as in 3.2 plus hilly area
The excluded instruments are as in 3.3 minus education plus distance to large city

## Table 4: Determinants of PUNISHMENT RATE

| Independent Variable | Eq.4.1 | Eq.4.2 |
|---|---|---|
| | 2.08 | 2.20 |
| **EDUCATION** | (0.700)*** | (0.607)*** |
| | -54.6 | -54.0 |
| **DENSITY** | (9.66)*** | (10.73)*** |
| | 3.19 | 2.84 |
| **WATER SOURCE** | (1.08)*** | (1.22)** |
| | | -0.53 |
| **DISTANCE** | - | 1.96 |
| | | 0.44 |
| **AGE** | - | (0..17)*** |
| | 23.00 | 2.32 |
| **CONSTANT** | (5.42)*** | (9.54) |
| **$R^2$** | 0.45 | 0.54 |

Note: Robust standard errors are in parentheses; *, **, and *** indicate that the estimated coefficients are significant at 10%, 5%, and 1% level.

## Table 5: Determinants of Log(SIZE)

| Independent Variable | Eq.5.1 | Eq.5.2 | Eq.5.3 |
|---|---|---|---|
| **Specification** | OLS | 2SLS | 2SLS |
| **EDUCATION** | -0.087<br>(0.042)** | -0.13<br>(0.048)*** | -0.14<br>(0.048)*** |
| **WATER SOURCE** | 0.190<br>(0.06)*** | 0.17<br>(0.07)** | 0.16<br>(0.06)** |
| **ALTERNATIVE SOURCE** | -1.42<br>(0.37)*** | -1.35<br>(0.41)*** | -1.34<br>(0.41)*** |
| **DENSITY** | 1.83<br>(0.61)*** | 1.77<br>(0.61)*** | 1.69<br>(0.80)*** |
| **HILLY AREA** | -3.76<br>(1.69)** | -3.52<br>(1.77)** | -3.60<br>(1.95)** |
| **DISTANCE** | - | - | 0.023<br>(0.094) |
| **CONSTANT** | 3:47<br>(0:25)*** | 3:77<br>(0:31)*** | 3:78<br>(0:31)*** |
| **$R^2$** | 0.81 | 0.80 | 0.80 |
| **Durbin-Wu-Hausman test (%sig)** | | 4.01(0.044) | 4.94 (0.026) |

Note: Robust standard errors are given in parentheses; *, **, and *** indicate that the estimated coefficients are significant at 10%, 5%, and 1% level.

## Table 6: Determinants of DRIP

| Independent Variable | Eq.6.1 | Eq.6.2 |
|---|---|---|
| **Specification** | OLS | 2SLS |
| **PRICE** | 0.65<br>(0.29)** | 0.86<br>(0.30)*** |
| **WATER THEFT** | - | -0.097<br>(0.049)** |
| **RED SOILS** | 0.14<br>(0.044)*** | 0.14<br>(0.040)*** |
| **RAINFALL** | -0.23<br>(0.008)*** | -0.20<br>(0.007)*** |
| **ADVERSE CLIMATE** | 0.040<br>(0.012)*** | 0.043<br>(0.011)*** |
| **ALTERNATIVE REVENUE** | 0.092<br>(0.020)*** | 0.093<br>(0.020)*** |
| **PREVIOUS SPRINKLER** | 0.56<br>(0.11)*** | 0.54<br>(0.11)*** |
| **HILLY AREA** | 0.44<br>(0.13)*** | 0.24<br>(0.19) |
| **CONSTANT** | -0.004<br>(0.034) | -0.017<br>(0.039) |
| **R2** | 0.84 | 0.86 |
| **Durbin-Wu-Hausman test(%sig)** | - | 0.004<br>(0.95) |

Note: Robust standard errors are in parentheses; *, **, and *** indicate that the estimated coefficients are significant at 10%, 5%, and 1% level.

**Table 7: Determinants of WATER THEFT, SIZE, PUNISHMENT RATE and DRIP**

| | WATER THEFT | log(SIZE) | PUNISHMENT RATE | DRIP |
|---|---|---|---|---|
| **WATER THEFT** | - | - | - | -0.094<br>(0.046)** |
| **log(SIZE)** | 0.121<br>(0.02)*** | - | - | - |
| **PUNISHMENT RATE** | 0.006<br>(0.002)*** | - | - | 0.00002<br>(0.001) |
| **DRIP** | 0.26<br>(0.102)*** | - | - | - |
| **PRICE** | 1.05<br>(0.53)** | - | - | 0.81<br>(0.23)*** |
| **DISTANCE** | 0.07<br>(0.0166)*** | 0.031<br>(0.057) | -0.62<br>(1.06) | - |
| **REVENUE SHOCK** | -0.032<br>(0.0125)** | - | - | - |
| **log(EQUIPPED SURFACE)** | -0.073<br>(0.02)*** | - | - | - |
| **ALTERNATIVE SOURCE** | - | -1.60<br>(0.162)*** | - | - |
| **WATER SOURCE** | - | 0.2<br>(0.04)*** | 3.00<br>(0.74)*** | - |
| **EDUCATION** | - | 0.086<br>(0.018)*** | 2.22<br>(0.317)*** | - |
| **AGE** | 0.006<br>(0.002)*** | - | 0.45<br>(0.093)*** | - |
| **HILLY AREA** | - | -4.00<br>(0.81)*** | - | 2.57<br>(0.125)** |
| **DENSITY** | - | 1.65<br>(0.52)*** | -55.00<br>(7.8)*** | - |
| **ALTERNATIVE REVENUE** | - | - | - | 0.085<br>(0.012)*** |
| **RAINFALL** | - | - | - | -0.02<br>(0.006)*** |
| **PREVIOUS SPRINKLER** | - | - | - | 0.53<br>(0.087)*** |
| **RED SOILS** | - | - | - | 0.14<br>(0.036)*** |
| **ADVERSE CLIMATE** | - | - | - | 0.047<br>(0.01)*** |
| **CONSTANT** | 0.11<br>(0.107) | 3.50<br>(0.17)*** | 2.00<br>(5.27) | 0.02<br>(0.057) |

Note: *, **, and *** indicate that the estimated coefficients are significant at 10%, 5%, and 1% level; Standard errors are given in parentheses.

## Appendix

### a. The Proof of the Proposition

At the initial contracting stage, the WA picks the monitoring level *m* and the price of water, *t* which maximizes the following social welfare function.

$$\max_{(m,t)} W^{cs}(m,t) = \left[2[g(q) - (c+\gamma)q - \kappa m f(q - q^{r})^{2} - \psi(m)]\right] \quad \text{(P)}$$

Its first-order conditions with respect to *m* and *t* are derived as follows;

1. First, we take the first partial derivative of the social welfare function, $W^{cs}(m,t)$ with respect to *m*

$$\frac{\partial W^{cs}(m,t)}{\partial m} = 2\begin{bmatrix} [g'(q^{cs}) - (c+\gamma) - 2\kappa m f(q^{cs} - q^{rcs})]\frac{\partial q^{cs}}{\partial m} + 2\kappa m f(q^{cs} - q^{rcs})\frac{\partial q^{rcs}}{\partial m} \\ -\kappa f(q^{cs} - q^{rcs})^{2} - \psi' \end{bmatrix} \quad \text{(A1)}$$

The first partial derivatives of the farmer's water use and report levels; $q^{cs}$ and $q^{rcs}$ with respect to *m* are given by:

$$\frac{\partial q^{cs}}{\partial m} = 0 \text{ and } \frac{\partial q^{rcs}}{\partial m} = \frac{1}{m}(q^{cs} - q^{rcs}) \quad \text{(A2)}$$

Replacing $\frac{\partial q^{cs}}{\partial m}$ and $\frac{\partial q^{rcs}}{\partial m}$ by their expressions into equation (A1) yields

$$\frac{\partial W^{cs}(m,t)}{\partial m} = 2[\kappa f(q^{cs} - q^{rcs})^{2} - \psi'(m)] = 0 \quad \text{(A3)}$$

Moreover, plugging $(q^{cs} - q^{rcs}) = \frac{t}{2\kappa m f}$ the amount of water stolen by the farmer into equation (A3), we obtain $\frac{\partial W^{cs}(m,t)}{\partial m} = 2\left[\frac{t^{2}}{4\kappa f m^{2}} - \psi'(m)\right] = 0$ (A4)

By rearranging equation (A4), the equilibrium monitoring effort is implicitly given by the following equation $\frac{t^{2}}{4\kappa f (m^{cs})^{2}} = \psi'(m^{cs})$ (A5)

2. Second, we take the first partial derivative of the function $W^{cs}$(m, t) with respect to *t*

$$\frac{\partial W^{cs}(m,t)}{\partial m} = 2\left\{[g'(q^{cs}) - (c+\gamma) - 2\kappa m f(q^{cs} - q^{rcs})\frac{\partial q^{rcs}}{\partial m}\right\} = 0 \quad \text{(A6)}$$

Remind that g' ($q^{cs}$) and the first partial derivatives of the farmer's water use and report levels, $q^{cs}$ and $q^{rcs}$ with respect to t are given by

$$g'(q^{cs}) = c + t; \frac{\partial q^{cs}}{\partial t} = \frac{1}{g''(q^{cs})} \text{ and } \frac{\partial q^{rcs}}{\partial t} = \frac{1}{g''(q^{cs})} - \frac{1}{2\kappa m^{cs} f} \quad \text{(A7)}$$

Substituting $g'(q^{cs})$, $\frac{\partial q^{cs}}{\partial t}$ and $\frac{\partial q^{rcs}}{\partial t}$ by their expressions given by equation (A7), one gets

$$\frac{\partial W^{cs}(m,t)}{\partial m} = 2\left\{\frac{(t-\gamma)}{g''(q^{cs})} - \frac{t}{2\kappa m^{cs} f}\right\} = 0 \qquad \text{(A8)}$$

By rearranging equation (A8) we obtain the equilibrium price of water

$$t^{cs} = \gamma\left(\frac{2\kappa m^{cs} f}{2\kappa m^{cs} f - g''(q^{cs})}\right) \qquad \text{(A9)}$$

The objective function is strictly concave since its Hessian matrix

$$D^2W(m,t) = \begin{pmatrix} -\frac{t^2}{\kappa f m^3} - 2\Psi''(m) & \frac{t}{\kappa f m^2} \\ \frac{t}{\kappa f m^2} & 2\left(\frac{1}{g''(q)} - \frac{1}{2\kappa m f}\right) \end{pmatrix}$$

is a negative definite for every (m; t). Indeed, its first and second principal minors are negative and positive respectively:

- The first principal minor is: $H_1 = \left[-\frac{t^2}{\kappa f m^3} - 2\Psi''(m)\right] < 0$

(Recall that the $\Psi$ (m) is increasing and convex).

- The second principal minor is

$H_2 = \det[D^2W(m,t)]$:

$$H_2 = \left[-\frac{t^2}{\kappa f m^3} - 2\Psi''(m)\right]\left(\frac{2}{g''(q)} - \frac{1}{\kappa m f}\right) - \left(\frac{t}{\kappa f m^2}\right)\left(\frac{t}{\kappa f m^2}\right) \qquad \text{(A10)}$$

Rearranging (A10) gives

$$H_2 = -\frac{1}{g''(q)}\left(\frac{2t^2}{\kappa f m^3} + 4\Psi''(m)\right) + \frac{2\Psi''(m)}{\kappa f m}$$

Which is unambiguously positive because it is the sum of two positive terms (i.e., the first term $-\frac{1}{g''(q)}\left(\frac{2t^2}{\kappa f m^3} + 4\Psi''(m)\right)$ is positive since g'' (q) < 0 and $\Psi$ (m)>0; and the second term $\frac{2\Psi''(m)}{\kappa f m}$ is positive).

Thus, the first-order conditions are both necessary and sufficient to identify a global maximum. This completes the proof of proposition 1.

**B. The Proof of Proposition 2**

Before solving the cooperative game, let us show how the total cooperative fine is distributed between cooperative members. Notice that the outlined cooperative framework implies that in the absence of any monitoring efforts, cooperative farmer members would share the cooperative fine equally. By monitoring each other, farmers reallocate the burden of the fine between themselves. Put differently, peer monitoring determines the *ex post* shares of the fine for everyone as well as the size of the expected punishment level. Denote by $s^{exp}_i(a_i; m_i ; a_j ; m_j)$ the farmer i's expected share of such a fine, where $a_k = (q_k \; q_k^r)$ is the amount of water stolen by farmer k, for k = i; j. Suppose, first, that only farmer i steals, i.e., $a_i > 0$ and $a_j$ 0, then the distribution of the fine is determined solely by the probability that farmer i is caught by her peer, $m_j$ $a_i$, which increases the expected share[33] of farmer i and decreases that of her peer, farmer j,

$$\begin{cases} \overset{\exp}{\underset{i}{S}} = \frac{1}{2}(1+\kappa m_j a_i) \\ \overset{\exp}{\underset{i}{S}} = \frac{1}{2}(1-\kappa m_j a_i) \end{cases} \quad \text{(B1)}$$

Now suppose that both farmers steal, i.e., $a_k > 0$ for k = *i; j*. The expected share[34] of farmer *i* is lowered by the likelihood of discovering the default of her peer, and is in turn increased by the likelihood that she herself is discovered stealing by her peer.

$$\overset{\exp}{\underset{i}{S}} = \frac{1}{2}(1-\kappa m_i a_j + \kappa m_j a_i) \quad \text{(B2)}$$

The sub-game perfect equilibrium corresponds to the profile ($m^c_1$; $m^c_2$; $q_1^c$; $q_2^c$; $q_1^{rc}$; $q_2^{rc}$) of monitoring efforts $\overset{i}{\underset{c}{m}} \in [0,\infty)$, water use levels $\overset{i}{\underset{c}{q}} : [0,+\infty)^2 \rightarrow [0,+\infty)$ mapping from the set of monitoring decisions into the set of water use decisions and water reports[35] $\overset{rc}{\underset{i}{q}} : [0,+\infty)^2 \rightarrow [0,q_i]$ mapping from the set of monitoring decisions into the set of reports. The objective function of farmer *i* is thus given by

$$U_i(m_i, q_i, q_i^r) = (g(q_i) - c(q_j) - t(q_j^r) - \frac{1}{2} f[1-\kappa m_j(q_i - q_i^r)][(q_i - q_i^r)(q_j - q_j^r)] - \psi(m_i) \quad \text{(B3)}$$

Now we solve the cooperative game by backward induction. At stage 2 of the game, farmer *i* optimally chooses the amount of water to use $q_i^c \equiv q_i^c(m_i, m_j)$ and the report to file, $q_i^{rc} \equiv q_i^{rc}(m_i, m_j)$ which maximize her expected payoff, given the levels of monitoring performed by the two cooperative members, $m_i$ and $m_j$ and that farmer j chooses $q^i \equiv q^i_c(m_i, m_j)$ and $q_j^{rc} \equiv q_j^{rc}(m_i, m_j)$,

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[33]The expected share of farmer *i* from the cooperative fine is given by $\overset{\exp}{\underset{i}{S}} = \kappa m_j a_i + \frac{1}{2}(1-\kappa m_j a_i)$ Where the first and second terms correspond respectively to her share when she is caught and when not. Analogously, farmer *j*'s expected share is given by $\overset{\exp}{\underset{j}{S}} = (1-\kappa m_j a_i) + \frac{1}{2}\kappa m_j a_i$

[34] The expected share of farmer i from the cooperative fine when everyone steals is given by $\overset{\exp}{\underset{i}{S}} = \frac{1}{2}(\kappa m_i a_j)(\kappa m_j a_i) + \kappa m_j a_i(1-\kappa m_i a_j) + \frac{1}{2}(1-\kappa m_i a_j)(1-\kappa m_j a_i)$

[35] Where the first term corresponds to her share when both farmers are caught stealing, the second term is her share when she is caught and farmer j not, and the last term is her share when none is caught. The set of reports is reduced to [0; qi] because it is assumed throughout this paper that there are no rewards for over-reporting.

$$\max_{q_i, q_i^r} U_i(m_i, q_i, q_i^r)$$

The first-order conditions with respect to $q_i$ and $q_i^r$ are respectively are given

$$q_i^c : g'(q_i) - c - \frac{1}{2}\kappa m_j f\left(\sum_{k=i,j}(q_k - q_k^r)\right) - \frac{1}{2} f[1 - \kappa m_i(q_k - q_k^r) + \kappa m_i(q_i - q_i^r)] = 0 \quad \text{(B4)}$$

And,

$$q_i^{rc} : -t + \frac{1}{2}\kappa m_j f\left(\sum_{k=i,j}(q_k - q_k^r)\right) + \frac{1}{2} f[1 - \kappa m_i(q_k - q_k^r) + \kappa m_i(q_i - q_i^r)] = 0 \quad \text{(B5)}$$

The objective function is strictly concave since its Hessian matrix of Ui (.,.), namely

$$D^2 U_i(q_i, q_i^r) = \begin{pmatrix} g''(q_i) - \kappa f m_j & \kappa f m_j \\ \kappa f m_j & -\kappa m_j f \end{pmatrix}$$

is negative definite[36]. Therefore, the first-order conditions are both necessary and sufficient to identify a global maximum.

To simplify our calculations in the remainder of this proof, we will replace in equations (B4) and (B5) the difference ($q_k$ $q_k^r$) for *k = i; j* by $a_k$ = ($q_k$ $q_k^r$) the amount of water stolen by farmer *k*.

$$q_i^c : g'(q_i) - c - \frac{1}{2}\kappa m_j f \sum_{k=i,j} a_k - \frac{1}{2} f(1 - \kappa m_i a_j + \kappa m_j a_i) = 0 \quad \text{(B'4)}$$

And

$$q_i^{rc} : -t + \frac{1}{2}\kappa m_j f \sum_{k=i,j} a_k - \frac{1}{2} f(1 - \kappa m_i a_j + \kappa m_j a_i) = 0 \quad \text{(B'5)}$$

At stage 1 of the game, farmer *i* chooses $m_i^c$ (given that farmer *j* chooses $m_j^c$) so as to solve

$$\max g(q_i) - cq_i - tq_i^r - \frac{1}{2} f(1 - \kappa m_i a_j + \kappa m_j a_i)(a_i + a_j) - \psi(m_i) \text{ for } i \neq j$$

This has the first order condition of;

$$\frac{\partial U_I^C}{\partial m_i} = \frac{1}{2}\kappa f(a_i + a_j)\left(a_j + m_i \frac{\partial a_j}{\partial m_i}\right) - \frac{1}{2} f(1 - \kappa m_i a_j + k m_j a_i)\frac{\partial a_j}{\partial m_i} - \psi'(m_i) \quad \text{(B6)}$$

Rewriting and rearranging equations (B.4) and (B.5) yields the system of the two equations as functions of the levels of theft $a_i$ and $a_j$

$$\begin{cases} 2\kappa m_j a_i + (\kappa m_j - \kappa m_i) a_j = \dfrac{2t - f}{f} \\ (\kappa m_i - k m_j) a_i + 2\kappa m_i a_j = \dfrac{2t - f}{f} \end{cases} \quad \text{(B7)}$$

[36] Since its first and second principal minors are negative and positive respectively, i.e., $H_1 = g''(q_i) - \kappa f m_j < 0$ and $H_2 = -g''(q_i)\kappa m_j t > 0$

Solving the above system gives the cooperative members' amounts of water stolen as functions of the levels of monitoring $m_i$ and $m_j$

$$a_i = \left(\frac{2t-f}{\kappa f}\right)\frac{(3m_i - m_j)}{(m_i + m_j)^2} \tag{B8}$$

$$a_j = \left(\frac{2t-f}{\kappa f}\right)\frac{(3m_j - m_i)}{(m_j + m_i)^2} \tag{B9}$$

By differentiating (B9) with respect to $m_i$ and $m_j$ respectively, one obtains

$$\frac{\partial a_j}{\partial m_i} = \left(\frac{2t-f}{\kappa f}\right)\frac{(m_i - 7m_j)}{(m_i + m_j)^3} \tag{B10}$$

$$\frac{\partial a_j}{\partial m_j} = \left(\frac{2t-f}{\kappa f}\right)\frac{(5m_i - 3m_j)}{(m_i + m_j)^3} \tag{B11}$$

By differentiating (B10) with respect to $m_i$ one gets

$$\frac{\partial^2 a_j}{\partial m_i^2} = \left(\frac{2t-f}{\kappa f}\right)\frac{(-2m_i + 22m_j)}{(m_i + m_j)^4} \tag{B12}$$

Now we differentiate (B6) with respect to $m_i$; which gives

$$\begin{aligned}\frac{\partial^2 U_i}{\partial m_i^2} &= \frac{1}{2}\kappa f\left[\left(2\frac{\partial a_j}{\partial m_i} + m_i\frac{\partial^2 a_j}{\partial m_i^2}\right)(a_i + a_j) + \left(a_j + m_i\frac{\partial a_j}{\partial m_i}\right)\left(\frac{\partial a_i}{\partial m_i} + \frac{\partial a_j}{\partial m_i}\right)\right] \\ &+ \frac{1}{2} f\left[k\left(a_j + m_i\frac{\partial a_j}{\partial m_i} - m_j\frac{\partial a_i}{\partial m_i}\right)\frac{\partial a_j}{\partial m_i} - (1 - \kappa m_i a_j + \kappa m_j a_i)\frac{\partial^2 a_j}{\partial m_i^2}\right] - \psi''(m_i)\end{aligned} \tag{B13}$$

We will focus on the symmetric sub-game perfect equilibrium where $m_i^c = m_j^c = m^c$ and $a_i^c = a_j^c = a^c$ which is given by:

- The equilibrium amount of water stolen

$$a^c = \frac{(2t-f)}{2\kappa m^c f} \tag{B14}$$

- The equilibrium monitoring effort $m^c$ is given by

$$m^c : \frac{(2t-f)(2f-t)}{4\kappa f m^2} = \psi'(m) \tag{B15}$$

Now we distinguish between two cases depending on the stringency of the punishment rate, f.

***Case 1: If*** $f \geq 2t$

The equilibrium amount of water stolen for a given level of monitoring will be non positive, i.e.,

$$a^c = \frac{(2t-f)}{2\kappa m^c f} \leq 0 \tag{B16}$$

Meaning that farmers will not gain from over-reporting since there are no rewards from doing so (by assumption). This implies that theft does not occur in equilibrium

$$a^c = 0 \qquad \text{(B17)}$$

By plugging equation (B14) into equation (B15), one gets the equilibrium intensity of monitoring given implicitly by

$$\frac{(2f - t)}{2m^c} a^c = \psi'(m^c) \qquad \text{(B18)}$$

It immediately follows from (B17) and (B18) that farmers do not monitor in equilibrium

$$m^c = 0 \qquad \text{(B19)}$$

***Case 2: If t < f < 2t***

The symmetric sub-game perfect equilibrium ($a^c$; $m^c$) is given by equations (B14) and (B15), where the equilibrium amount of water stolen is positive

$$a^c = \frac{(2t - f)}{2\kappa m^c f} > 0$$

And the first-order condition for the level of monitoring $m^c$ which is given by (B15) is also sufficient because the second partial derivative of the farmer's utility function is negative

$$\frac{\partial^2 U_i}{\partial m_i^2}(m^c, a^c) = \left(\frac{2t - f}{\kappa f}\right)\left(\frac{t - 3f}{4(m^c)^3}\right) - \psi''(m^c) < 0 \qquad \text{(B20)}$$

This completes the proof of proposition 2.

**C. Cooperative Size**

In the n-farmer cooperative, we focus on mutual peer monitoring, whereby each farmer monitors all her peers[37]. We assume that each farmer applies equal monitoring efforts to monitor all her peers[38], which implies that the total cost of monitoring applied by a farmer, say farmer *i* is equal to $\psi[(n-1)m_i]$. The joint-responsibility clause states that a farmer pays $\frac{1}{n}$ of the cooperative fine in either case, all farmers are caught stealing or none is caught. The farmer bears $\frac{1}{n-\kappa}$ of the fine if she is caught and also (n-k-1) of her peers are also caught, for k = 1,…, n-2. She bears the whole fine if she is the only one who was caught and pays nothing if she is not caught and her (n-1) peers are caught.

Let $\rho_i^C$ and $\rho_i^N$ denote the probabilities of the events when farmer *i* is caught/not caught stealing in the cooperative. If $p_{ij} = \kappa m_j a_i$ is the probability that farmer *i* is caught by her peer, farmer j, then $\rho_i^C$ and $\rho_i^N$ are defined as follows:

$$\rho_i^C = \prod_{l \neq i}(1 - p_{il})$$

[37] See Armanderiz de Aghion (1999) for other monitoring structures which could be more effcient than mutual monitoring.

[38] Here we should clarify that we didn't claim that it is efficient to assume that each farmer applies equal monitoring to all her peers. We made this assumption to avoid technical difficulties. One plausible explanation on the face of it is: in the symmetric setting (cooperative members are identical) we can have symmetric and asymmetric equilibria. Since we focus on the symmetric equilibrium, then it is seems quite plausible to assume that every cooperative member monitors all her peers with the same intensity

$$\rho_i^N = 1 - \prod_{i \neq l} (1 - p_{il})$$

Notice that farmer *i* is caught, if she is caught at least by one of her peers. In order to determine farmer *i*'s expected share of the cooperative fine, we proceed by iteration[39] ; this implies that this share is equal to

$$S_i^n = \frac{1}{n}\left\{\prod_{s\neq i}\rho_s^N + \rho_i^C\left[1 + \frac{1}{C_{n-1}^1}\sum_{s\neq i}\rho_s^N + \frac{1}{C_{n-1}^2}\sum_{s_1\neq s_2\neq i}\rho_{s_1}^N\rho_{s_2}^N + \ldots + \frac{1}{C_{n-1}^{n-2}}\sum_{s_1\neq s_2\neq\ldots\neq s_{n-2}}\rho_{s_1}^N..\rho_{s_{n-2}}^N\right]\right\}$$

(C1)

Now let us derive the optimal water use level, report and monitoring effort.

At stage 2 of the game a farmer, say farmer i, chooses $q_i$ and $q_i^r$ so as to maximize her expected payoff, given the monitoring efforts profile $(m_i^c, m_{-1}^c) \in [0,+\infty)^n$ applied at the first stage of the game and also that her (n 1) peers choose the water use levels profile $q_{-i}^c \in [0,+\infty)^{n-1}$ and the profile of reports $q_{-i}^{rc} \in (0, q_i \times \ldots \times (0, q_{i-1}) \times (0, q_{i+1}) \times \ldots \times (0, q_n)$

$$\max_{(q_i, q_i^y)} g(q_i) - cq_i - tq_i^r - S_i^n(m_i, a_i, m_{-i}, a_{-i}) f\left(\sum_{j=1}^n a_j\right) - \psi[(n-1)m_i]$$

The optimal water use level $R_i$ ($m_i$,$m_{-i}$) is given by

$$g'(R_i) = c + \frac{\partial S_i^n(m_i, a_i, m_{-i}, a_{-i})}{\partial q_i} f\left(\sum_{j=1}^n a_j\right) + S_i^n(m_i, a_i, m_{-i}, a_{-i}) f$$

The optimal farmer's report $R_i^r$ ($m_i$, $m_{-i}$) is given by

$$t = \frac{\partial S_i^n(m_i, a_i, m_{-i}, a_{-i}) f}{\partial q_i^r}\left(\sum_{j=1}^n a_j\right) + S_i^n(m_i, a_i, m_{-i}, a_{-i}) f$$

At the second stage of the game, farmer i chooses $m_i \in [0,+\infty)$ so as to maximize her utility function, given that her (n-1) peers apply the monitoring efforts profile $m_{-i}^c \in [0,+\infty)^{n-1}$

[39] We start with the three-farmer case. The probabilities of the events when farmer i is caught/not caught stealing in this case are defined respectively by

$$\rho_i^C = 1 - \rho_i^N = p_{ij} + p_{ik} - p_{ij} p_{ik}$$

$$\rho_i^N = (1 - p_{ij})(1 - p_{ik})$$

Where $i \neq j \neq k$ from now on. Taking into account the punishment sharing rule and the fact that the events of catching farmer i; farmer j and farmer k are independent, the expected share for farmer i from the total fine, $S_i^3$ is

$$S_i^3 + \frac{1}{3}\left\{\rho_j^N\rho_k^N + \rho_i^C[1 + \frac{1}{2}(\rho_j^N + \rho_k^N)]\right\}$$

Analogously, for the four-farmer cooperative, the expected share of the cooperative fine is given by

$$S_i^4 = \frac{1}{4}\left\{\rho_j^N\rho_k^N\rho_l^N + \rho_i^C[1 + \frac{1}{3}(\rho_j^N + \rho_k^N + \rho_l^N) + \frac{1}{3}\rho_j^N\rho_k^N + \rho_j^N\rho_l^N + \rho_k^N\rho_l^N\right\}$$

$$-\frac{\partial S_i^n(m_i,a_i;m_{-i}^c;a_{-i})}{\partial m_i} f\sum_{j-1}^{n} a_j - S_i^n(m_i,a_i;m_{-i}^c;a_{-i}) f\sum_{j\neq i}\frac{\partial a_j}{\partial m_i} = (n-1)\psi'[(n-1)m_i]$$

Similarly to what has been done previously, we will proceed by iteration to determine the sub-game perfect equilibrium in the symmetric case for the n-farmer cooperative[40]

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[40] We start with the three-farmer case. Farmer *i* optimally chooses $q_i^c$ and $q_i^{rc}$

$$q_i^c : g'(q_i) = c + \frac{\partial S_i^3}{\partial q_i} f(a_i + a_j + a_k) + S_3^{e\chi} f$$

$$q_i^{rc} : t = -\frac{\partial S_i^3}{\partial q_i} f(a_i + a_j + a_k) + S_3^{e\chi} f$$

Where, one uses the fact that $\frac{\partial S_i^3}{\partial q_i} = -\frac{\partial S_i^3}{\partial q_i} = \frac{\partial S_i^3}{\partial a_i}$ and that

$$\frac{\partial S_i^3}{\partial a_i} = (pm_j + pm_k - p^2 m_j m_k a_i)\left[1 + \frac{1}{2}\begin{pmatrix}(1-\kappa m_i a_j)(1-\kappa m_k a_j)\\ +(1-\kappa m_i a_k)(1-\kappa m_j a_k)\end{pmatrix}\right]$$

And at stage 1 of the game, farmer *i* optimally chooses $m_i^c$ that satisfies

$$\mathrm{m}_i^c : \frac{\partial S_i^3}{\partial m_i} f(a_i + a_j + a_k) - S_i^3 f\left(\frac{\partial a_j}{\partial m_i} + \frac{\partial a_k}{\partial m_i}\right) = 2\psi'(2m_i)$$

Where

$$\frac{\partial S_i^3}{\partial m_i} = \frac{1}{3}\left\{\begin{matrix}
-\kappa a_j(1-\kappa m_k a_j)(1-\kappa m_i a_k)(1-\kappa m_j a_k)\\
-\kappa a_k(1-\kappa m_i a_j)(1-\kappa m_k a_j)(1-\kappa m_j a_k)\\
+(\kappa m_j a_i + \kappa m_k a_i - \kappa^2 m_j m_k a_i^2\\
\begin{bmatrix} 1 \\ +\frac{1}{2}(-\kappa a_j(1-\kappa m_k a_j) - \kappa a_k(1-\kappa m_j a_k)) \end{bmatrix}\\
-\kappa m_i \frac{\partial a_j}{\partial m_i}(1-\kappa m_k a_j)(1-\kappa m_i a_k)(1-\kappa m_j a_k)\\
-\kappa m_k \frac{\partial a_k}{\partial m_i}(1-\kappa m_i a_j)(1-\kappa m_i a_k)(1-\kappa m_j a_k)\\
-\kappa m_j \frac{\partial a_k}{\partial m_i}(1-\kappa m_i a_j)(1-\kappa m_i a_k)(1-\kappa m_k a_j)\\
+(\kappa m_j a_i + \kappa m_k a_i - \kappa^2 m_j m_k a_i^2\\
\left[\frac{1}{2}\begin{pmatrix} -\kappa m_i \frac{\partial a_j}{\partial m_i}(1-\kappa m_k a_j) - \kappa m_k \frac{\partial a_j}{\partial m_i}(1-\kappa m_i a_j)\\ -\kappa m_i \frac{\partial a_k}{\partial m_i}(1-\kappa m_j a_k) - \kappa m_j \frac{\partial a_k}{\partial m_i}(1-\kappa m_i a_k)\end{pmatrix}\right]
\end{matrix}\right\}$$

In the symmetric equilibrium one gets: $q_3^c : g'(q) = c + t$

$$q_3^{rc} : t = 2\kappa f m a \phi_3(\kappa m a) + \frac{1}{3} f$$

$$m_3^c : 2\psi'(2m) = 2\kappa f a(a + 2m\beta_3)\phi_3(\kappa m a) + \frac{2}{3} f\beta_3$$

$$q_n^c : g'(q) = c + t \tag{C2}$$

$$q_n^{rc} : t = (n-1)\kappa f m a_n^c \phi_n(\kappa m a_n^c) + \frac{1}{n} f \tag{C3}$$

$$m_n^c : (n-1)\psi'[(n-1)m] = (n-1)\kappa f a_n^c (a_n^c + 2m\beta_n)\phi_n(\kappa m a_n^c) + \frac{(n-1)}{n} f\beta_n \tag{C4}$$

Where $\phi_n(\chi) = (1-\chi)^{(n-2)} \sum_{k=1}^{n-2} (1-\chi)^{(n-1)(k-1)}$ and $\beta_n = \frac{\partial a_j^c}{\partial m_i}(m_n^c, q_n^c)$ for $i \neq j$.

As one can see, there are such technical complications which make it quite difficult to determine an analytical solution to this problem. That is why we will resort to simulations to characterize the solution to this problem.

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Where $\phi_3(\chi) = (1-\chi)[1+(1-\chi)^2]$ and $\beta_3$ measures the impact of a farmer's monitoring effort on her peer's incentives of theft.

$$\beta_3 = \frac{\partial(q_i - q_j^r)}{\partial m_i}(m_3^c, q_3^c) \text{ for } i \neq j$$